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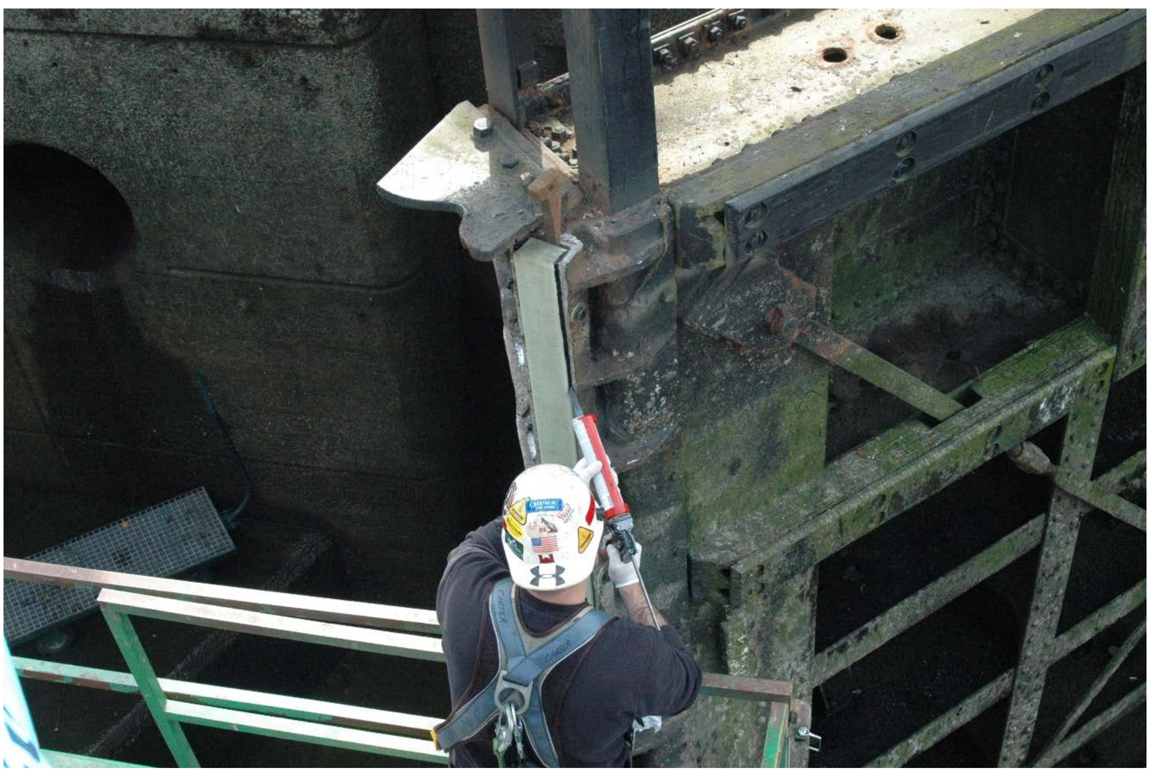
Monitoring Completed Navigation Projects (MCNP) Program

Evaluation of Sealing Materials and Techniques for Installing Quoin and Miter Block Backing Grout

Stuart Foltz, Jonathan Trovillion, and Jeffrey Ryan

November 2015



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Abstract

Unified Facility Guide Specifications (UFGS) 35 20 16.33 “Miter Gates,” specifies two types of filler materials to set miter and quoin contact blocks: epoxy and zinc. Zinc is rarely used today for safety reasons. While the epoxy filler stipulated in the guide specification is no longer available, the UFGS does permit the use of an equal product, and several are being used effectively in the field. The materials currently in use have low viscosities and are typically poured behind the quoin and miter blocks in sections. Gaps are typically sealed with commercial fillers. Often, the surface preparation on the quoin block and channel is not ideal for proper adhesion. This is not a problem for the epoxy filler materials since they are applied in a confined space and are loaded in compression. However, the sealing materials can fail as the pressure head of the epoxy material increases while it is being poured. This pressure can cause the epoxy material to leak out. When this happens, the gap must be cleaned and resealed. This work was undertaken to resolve the problems associated with pouring epoxy fillers, and to recommend improvements to the process.

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Preface

The studies reported herein were conducted as part of the U.S. Army Corps of Engineers (USACE) Monitoring Completed Navigation Projects (MCNP) Program. The USACE MCNP Program is administered at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS, under the Navigation Research, Development, and Technology Transfer (RD&T) Program. At the time this effort was conducted, Jeffrey A. McKee was the Headquarters, USACE (HQUSACE) Navigation Business Line Manager overseeing the MCNP Program. W. Jeff Lillycrop, CHL, was the ERDC Technical Director for Civil Works and Navigation RD&T. Dr. Lyndell Z. Hales, CHL, was the USACE MCNP Program Manager, and Dr. John E. Hite, CHL, was the MCNP Navigation Structures Focus Area Manager.

These research studies were conducted by the ERDC Construction Engineering Research Laboratory (CERL), Champaign, IL, during the period 1 October 2011 through 30 September 2014 under Project 399320, Sealing Techniques. The work was performed, and this report was written, by Stuart Foltz, Jonathan Trovillion, and Jeffrey Ryan of the CERL Materials and Structures Branch (CF-M), Facilities Division (CF). At the time of publication of this report, Vicki VanBlaricum was Chief, CF-M; Donald K. Hicks was Chief, CF; and Kurt Kinnevan was CERL Technical Director for Installations. The Deputy Director of CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was Director of ERDC.

1 Introduction

1.1 Background

Unified Facility Guide Specifications (UFGS) 35 20 16.33 “Miter Gates,” specifies two types of filler materials to set miter and quoin contact blocks: epoxy and zinc. Zinc is rarely used today for safety reasons. While the epoxy filler stipulated in the guide specification is no longer available, the UFGS does permit the use of an equal product, and several are being used effectively in the field. The materials now used have low viscosities. They are typically poured behind the quoin and miter blocks in lifts. The perimeter of the filled volume is typically sealed with commercial fillers such as Bondo®.

Often, the surface preparation on the quoin block and channel is not ideal for proper adhesion. This is not a problem for the epoxy backing materials since they are applied in a confined space and are loaded in compression. However, the sealing materials can fail as the pressure head of the epoxy material increases while it is being poured. This pressure can cause the epoxy material to leak out. When this happens, the gap must be cleaned, resealed, and allowed to cure. In some cases, the quoin or miter block must also be removed, cleaned, and reset — an additional process that causes even more delay. This work was undertaken to investigate best practices for sealing techniques and materials selection to resolve construction problems associated with this use of epoxy backing materials.

1.2 Objectives

The objectives of this work were to investigate and recommend best practices for sealing the perimeter of cavities behind quoin and miter blocks before pouring backing materials in those gaps. Various commercially available materials were tested and evaluated for suitability. These objectives included investigating all issues related to pouring the epoxy material in the gap, including:

- bleeding of material through small holes
- sealant “blowout”
- voids remaining due to the epoxy not passing narrow openings
- temperature issues
- lift height for each pour
- time between pouring lifts.

1.3 Approach

The objectives of this work were accomplished in three primary thrusts.

First, to gauge the extent of the problem across the U.S. Army Corps of Engineers (USACE), preliminary information was gathered regarding problems encountered while pouring epoxy quoin backing. Researchers attended a lock maintenance workshop and conducted a phone survey.

Second, experimental mock-up test facilities were constructed in multiple configurations, including one setup using quoin blocks from Nickajack Lock and Dam (L&D), a multi-purpose project in Marion County, TN. Channel sections were constructed to match the block dimensions. A second configuration was constructed using smaller steel plates with various bolt and filling holes to test the sealing materials. Each configuration was connected to clear vinyl tubing for filling and applying head pressure. After materials were allowed to cure, they were tested under water pressure to investigate their sealing properties. Successes and failures of the various materials and filling processes were recorded, and attempts were made to improve performance by altering application processes.

Third, smaller scale tensile adhesive tests were conducted. Since the results in the mock-up tests were inconclusive, further testing was needed to gain more confidence in the findings. While the mock-up tests allowed a good demonstration of application of the materials, there were multiple shortcomings regarding quantification of the material performance, including:

1. The inability to measure the tensile adhesion of the material to the steel surfaces.
2. The fact that the steel plates were composed of carbon steel, which did not allow verification of applicability to stainless steel.
3. While the application temperatures were recorded, there was not adequate data to gain confidence in how the materials would perform at different temperatures. One or sometimes two tests did not always create confidence in how the material would perform at that application temperature.
4. At least one material showed large variations in performance among tests. The tensile adhesion tests used 2-in. diameter pucks that were adhered using the test materials and tested in tension using a tensile-compression machine. This allowed the test materials to be conditioned at various temperatures and cured at those temperatures in multiple tests. Pucks were fabricated from

both carbon steel and stainless steel. Initial demonstration of this test indicated it was a good complement to the tests using the steel plates.

1.4 Mode of technology transfer

This technology will be transferred directly to the customer — District personnel responsible for specifying and installing quoin and miter blocks with backing materials. Guidance will be provided on sealant materials selection and application. The media for this transfer will be primarily through Headquarters, U.S. Army Corps of Engineers (HQUSACE) Engineering Technical Notes, Technical Reports, and technical presentations to engineering audiences such as the annual Great Lakes and Ohio River Division (LRD) Lock Maintenance Workshop.

1.5 Terminology

Manufacturers sometimes use different terms to denote the time-temperature relationship that describes how their products cure. This report used industry-standard definitions when possible. For terms without industry-standard definition, the following short glossary is provided to clarify the terminology used in this report:

- *Working (pot) life*. (ASTM C-881). The time after mixing, during which a bonding system or mixture containing it retains sufficient workability for proper use.
- *Tack free*. The time when a finger can touch the surface without adhering or being sticky. This term is generally used in reference to paints.
- *Skin time*. This applies to air cure materials that cure from outside in and first form a skin before fully curing. It is similar to tack free, but is generally used in reference to thicker materials.
- *Gel Time*. (ASTM C-881). The gel time is the interval between the beginning of mixing and the formation of the gelatinous mass.
- *Cure time*. The time it takes for the product to reach its final strength.

2 Survey of Issues

The work documented in this report was initiated to meet the expressed concern of USACE District(s) regarding the need to improve the construction process for applying quoin and miter contact block backings. This chapter documents an investigation of those issues and stated concerns regarding these backing materials. This work focused primarily on the process of sealing the backing area before pouring epoxy backing. For example, the diagonal cross-hatched areas shown in Figures 2-1 and 2-2 would be filled with epoxy grout backing and the perimeter would need to be sealed to prevent the grout from leaking until it is set.

Figure 2-1. Typical quoin blocks.

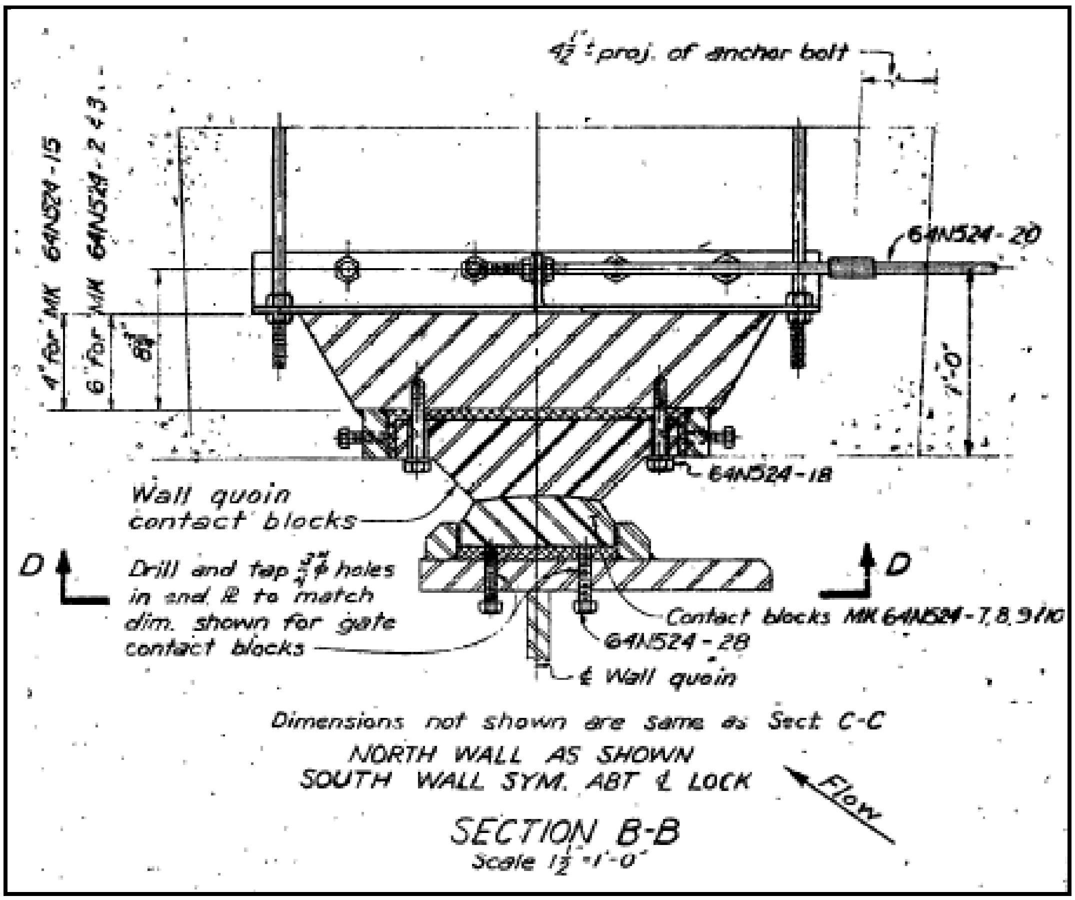
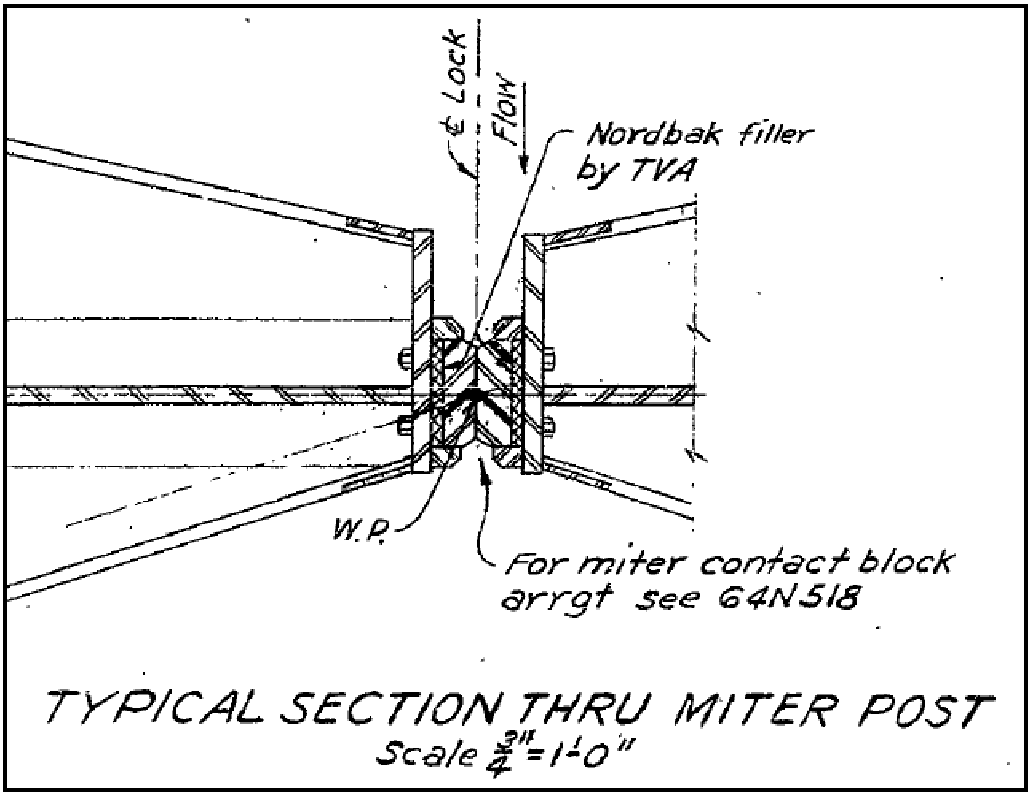


Figure 2-2. Typical miter blocks.



2.1 Lock maintenance workshop

CERL researchers attended the LRD Lock Maintenance Workshop in February 2012. At the workshop, a number of CERL projects were briefly introduced in one combined informal presentation. Following the presentation, survey questionnaires were distributed pertaining to most of the presented projects, including this project on quoin and miter contact block epoxy backing. The responses and other user feedback, which reflected a diversity of field experiences, guided this investigation.

2.2 Site visits

Before the Lock Maintenance Workshop, researchers made site visits to Smithland L&D, operated by the USACE Louisville District, and to the Kentucky L&D, operated by the Nashville District, to visually inspect the quoins and discuss both related and unrelated issues at these sites. Smithland L&D is located on the Ohio River at mile 918.5 below Pittsburgh, PA and 62.5 miles upstream of the confluence of the Ohio and Mississippi rivers. The Kentucky Lock is located near Gilbertsville, KY, 22.4 miles from the confluence of the Tennessee and Ohio Rivers and 20 miles east of Paducah, KY.

The workshop included a visit to Olmsted L&D, operated by the Louisville District, about 17 miles upstream from the confluence of the Ohio and Mississippi rivers. These site visits were useful additions to the workshop, but only provided a look at constructed quoins.

In May 2012, researchers made site visits to Wilson L&D (dewatered), and Wheeler L&D (operational). Wilson L&D, which is operated by the Nashville District, is located on the Tennessee River near Florence, AL. This lock was dewatered and some of the quoin blocks had been removed for repairs. However, the condition of the blocks removed for replacement was not observed, and there was no active work installing quoin blocks during the site visit. Wheeler L&D is also operated by the Nashville District and is located on the Tennessee River, near Decatur, AL

In February 2013, researchers visited L&D 27, which is operated by the St. Louis District and is located in Granite City, IL. At that time, the main lock chamber had been dewatered for replacement of the lower miter gates. Researchers observed the installation of the quoin and miter contact block backing material using Loctite® Nordbak® High Performance Backing, a two-part epoxy compound. The Nordbak® was stored in a heated gatehouse until used. One bucket of Nordbak® was mixed and poured into each contact block void each hour from the top of the gates.

During application, outdoor temperatures were 25 to 35 °F (-4 to 2 °C) with periodic rain and snow. Heaters were used on the downstream side. Temporary shelter was provided to protect the work from the cold and wet. Plastic tarps were hung over the downstream and some upstream sides of the contact blocks. Canopies were placed on the gates over the tops of the blocks. There were no apparent problems with the Nordbak® backing, but numerous problems occurred with the sealants used to contain the backing until it hardened. Mainly, the use of a one-component caulk tube product resulted in numerous blowouts that released the backing material (see Figure 2-3). Although temperature was likely a factor, it was also likely that the failures were caused by pouring the Nordbak® while the sealing product was cured at the surface, but still soft and uncured in the middle.

Figure 2-3. Backing material blowouts and leakage.

2.3 Phone interviews

Many individuals from 12 Districts (five Divisions) were interviewed by phone. Questions covered a range of topics, including: types of quoin backing materials used, kinds of material testing, long-term performance of materials, construction issues (including the sealants used), problems encountered while pouring the materials, lift height, and time between pours.

Respondents reported frequent problems with the epoxy leaking out of small gaps or larger openings due to sealant failure. Some also reported voids where the material did not fill the entire area behind the contact block. These problems seem nearly mutually exclusive, but they exist nonetheless. When mixed to pour, the backing material seems thick and viscous; it might not penetrate small gaps and leave voids. Voids could be caused by entrapped air. At L&D 27, researchers confirmed leakage at "pinholes" by observation, although under those environmental conditions, the leakage through pinholes was minimal. The horizontal joints between the stacked blocks were unsealed. Leakage (also minimal) was observed at these locations.

Application processes vary. Some Districts pour the epoxy backing from the top of the gate. Others attempt to reduce voids by attaching a funnel to openings in the contact blocks lower on the gate. At least one District pours the entire contact block space with epoxy in one lift on high lift gates.

This work found no products specifically marketed for use in applications like sealing a cavity on miter gates to be pressurized by a fill material. In fact, Districts use many different materials. In one case, a sealer was chosen simply because it was readily on hand. Survey respondents reported using a range of materials: Bondo®, silicone caulk, auto windshield sealant, Hilti Anchor Epoxy, Belzona 4111 Magma Quartz, and Splash Zone A788 marine putty. Most (not all) of these products are two-component materials.

3 Sealing Material Testing

3.1 Sealant materials selection

When placing miter gate contact block epoxy backing materials, USACE has most frequently used Bondo® to seal the perimeter of the cavity to contain the backing material when it is first poured in. Bondo® has many desirable properties, including excellent adhesion to steel and a quick set. However, Bondo® is also time-consuming to mix and has a short working time, especially as higher temperatures. Some difficulties using Bondo® have been reported.

Work documented in this report focused on indentifying alternatives to Bondo® that might be easier to use and give more reliable results. The work also identified numerous issues that could affect the success of both Bondo® and the alternatives. All-purpose adhesives and caulks were tried, but the primary focus of this investigation gradually shifted to two-part grouts and adhesives in cartridges applied by applicator gun. Testing was able to determine that some materials were more appropriate than others, but there was no clear indication of which materials would work without additional testing. Section 3.2 describes some of the chemistry involved in success of the material alternatives.

3.2 Sealing adhesion properties

Adhesion of a polymeric material to a metallic surface is a complicated matter with many considerations such as substrate chemistry, polymer chemistry, bond forces (Van der Waals, ionic, covalent), surface cleanliness, and surface profile, to name a few. Polymer chemists can control a certain amount of adhesion by manipulating what and how many pendants are on the polymer backbone to promote the most optimal adhesive bond via Van der Waals (hydrogen) or ionic forces. Chemists can also add some adhesion promoting components such as silane, which forms a much stronger covalent bond than the Van der Waals or ionic bond to carbon steel. However, what may bond well to carbon steel may not bond well to stainless steel, aluminum, etc. Impurities on a metallic surface, such as a thin layer of oxides, have been shown to promote adhesion, whereas a thick oxidative layer, like pack rust, will cause very poor adhesion. Likewise, an ultraclean metallic surface prepared in a strong vacuum has been shown to have poor adhesion as well. Paints and coatings for industrial steel applications have a stronger adhesion to a sand-blasted surface, which creates an approximate 1.5-3 mil angular profile. This is due to the increased surface area and possible mechanical interlocking of the polymer film with the angular profile (butt joint). Due to the many variables that dictate adhesion, it is virtually impossible to gauge a polymer materials adhesive strength to a metallic surface based solely on its chemical composition. Epoxies, polyurethanes, polysiloxanes, acrylics, etc. have a wide range of chemistries among each group as well as between manufacturers. It is therefore necessary to conduct laboratory testing in which as many variables as possible can be controlled to get a reliable adhesion value for one type of polymer chemistry to a particular metallic surface.

3.3 Testing setups

Quoin and miter blocks were obtained from Nickajack Lock and Dam (USACE Nashville District, Jasper, TN) for use in a mock setup to test sealing techniques. Initially it was unclear how to use these components in a test setup or what tests should be performed on the sealing materials. First, it was decided to apply a hydraulic load in the cavity for the backing material. Section 3.3.1 provides further details. After testing materials using these setups, it was decided that a simpler test was needed to more easily test in a range of controlled temperatures, gather more objective performance data, and allow a greater number of tests under the budget limitations. These tension tests, which are further described in Section 3.3.2, proved to be less objective than desired, but nevertheless complemented the mock quoin block tests quite well.

3.3.1 Quoin block and mock quoin block test setups

In particular, the biggest single question may have been how to apply a hydraulic head to the sealant enclosing the backing material cavity. It was determined that a threaded hole in the block could be connected to a pipe or tube and extended above the fixture. A clear vinyl tube was used. The open end, which was attached to an overhead crane, could be raised to apply 32 ft of head at the test block connection. Any leakage gradually reduced the water level.

Because of the size of the contact blocks, it was decided that a simpler mock-up might also be useful. Two plates were used. One plate has a length and width 1-in. greater to form a “corner” when the plates are placed together. The design of this simpler version also allowed easy variation of the distance between the plates, which determines the width of the gap to be caulked. Preliminary tests were run using clear plastic plates to address certain concerns before steel plates were constructed. The clear plastic also allowed the best access to observe the behavior of the sealant as the hydraulic load is applied (Figure 3-1).

Follow-on tests using steel plates were necessary because sealant adhesion would be different for the plastic and steel substrates. Figure 3-2 shows the steel plate test setup. Figure 3-3 shows the schematic drawings of the plastic and steel plates. Figure 3-4 shows the setup using actual contact blocks. Tests were run using the plastic, steel plates, and the C-channel with a stainless block. Cleanup of the steel after a test often required substantial abrasion that polished the steel. To make the tests more realistic, the cleaned plates were left covered by wet rags overnight. They were wiped off before the next test, but the steel was mildly corroded.

Because of the size of the quoin blocks, there was a concern that, if epoxy were poured into the block and channel, it might be difficult to separate them. Water was used instead of epoxy to perform the pressure tests. The plate configurations were also tested using water. Water has a slightly lower density than epoxy, but because it is less viscous, it may result in a slightly more stringent test. Nevertheless, the results using water were informative.

Figure 3-1. Plexiglass plate setup.

Figure 3-2. Steel plate setup.

Figure 3-3. Schematic of quion test plates.

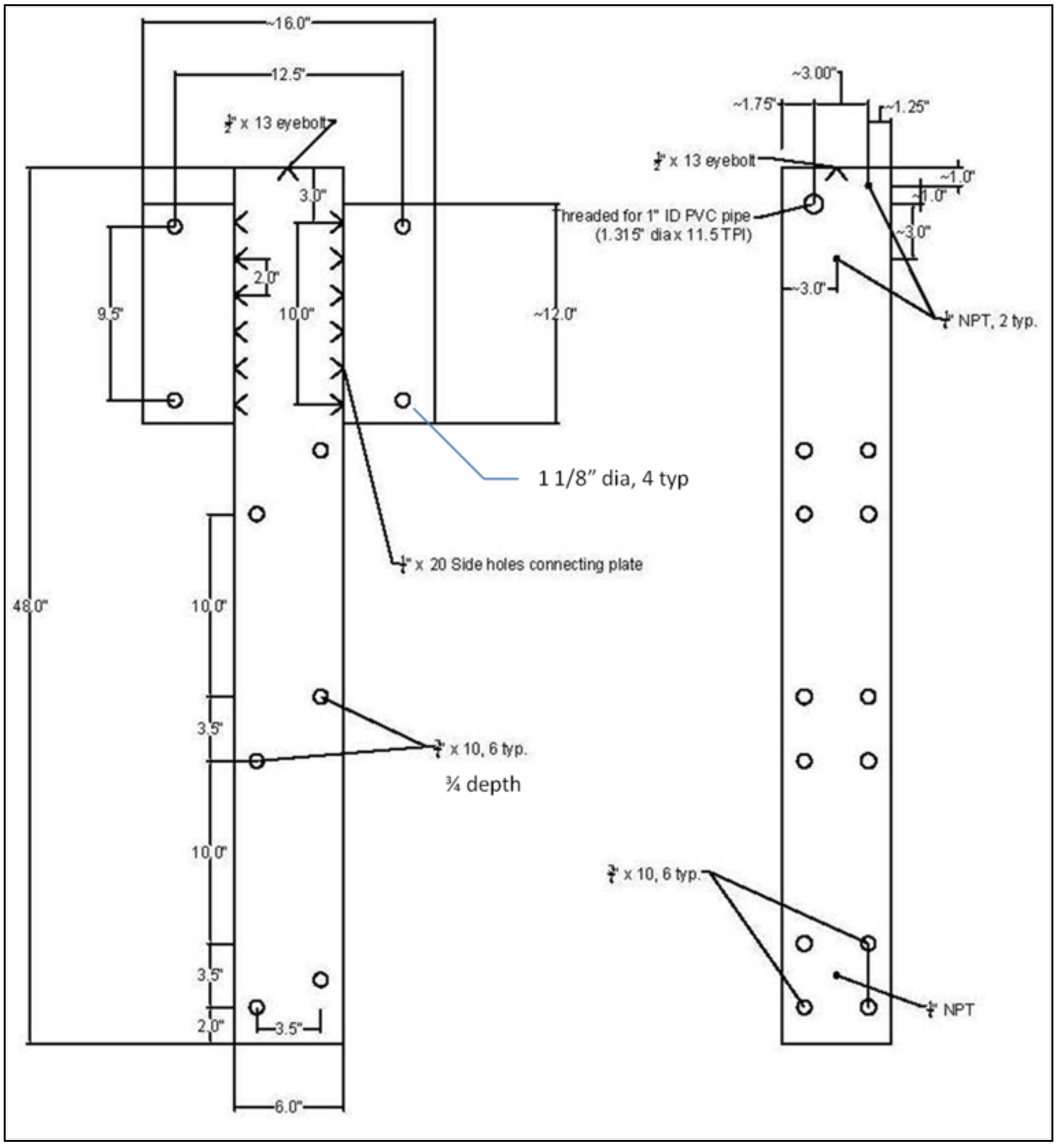


Figure 3-4. Stainless contact block and C-channel setup.

3.3.2 Tension test setup

After most of the tests using the mock quoin blocks were completed, it was determined that a simpler test was needed. A tension test was designed and used. Figure 3-5 shows the test setup. Pucks of a 2 in. diameter were fabricated in both carbon and stainless steel.

Figure 3-5. Tension test setup.

3.4 Testing

3.4.1 Quoin block and mock quoin block testing

Products were tested under various conditions using these test setups. The gap between the two plates was generally set at 3/16 in. Water was used to fill the interior void similar to epoxy backing material. Because water is less viscous than epoxy backing, this test is more stringent than the application it is intended to model. Although water is less dense, the head pressure applied was also greater than what would typically be applied during construction.

3.4.2 Tensile testing

Although the quoin block and mock quoin block tests gave leak/no leak results that were definitive for the blocks that leaked, most materials passed this test and further discrimination was subjective. As these tests were performed, it was thought that repetition of the test under the same and additional environmental conditions (temperatures) would improve the results. This may be true, but it was decided that the improvement might not be worth the cost in time and money. As a result, an alternative test using tensile samples was considered, trialed, and used. Tensile testing performed in a tensile-compression testing machine provided a quantitative measure of adhesion at the weakest point, whether that be within the material or at a steel interface. This test was much simpler, quicker, and could be economically repeated multiple times at various temperatures.

Used alone, the tensile tests might not be adequate to conclude which materials would be best. As a complement to the sealed joint pressure test, the results still did not provide an objective measure of what materials were satisfactory, but the knowledge gained gives a good indication of what the best choices are.

After some pilot tests, the majority of the testing was done after cleaning the pucks to a smooth surface and then wetting the test surface of the carbon steel pucks for approximately 48 hours to develop light surface rust. Test material was applied between the pucks in a thickness that was approximately ⅛ to $^{3}/_{16}$ in. Testing was completed while varying temperatures between 36 °F (2 °C), room temperature (70-75 °F [21-24 °C]) and 90 °F (32 °C). The low temperature used for Bondo® and A788 was 59 °F (15 °C) due to limitations of the low temperature cure for these materials.

The tensile tests were performed on most materials under five conditions:

- Tested material conditioned at room temperature, pucks conditioned at room temperature, and test material cured at room temperature.
- Tested material conditioned at room temperature, pucks conditioned at 36 °F (2 °C) (or 59 °F [15 °C]), and test material cured at 36 °F (2 °C) (or 59 °F [15 °C]).
- Tested material conditioned at room temperature, pucks conditioned at 90 °F (32 °C), and test material cured at 90 °F (32 °C).
- Tested material conditioned at 36 °F (2 °C), pucks conditioned at 36 °F (2 °C) (or 59 °F [15 °C]), and test material cured at 36 °F (2 °C) (or 59 °F [15 °C]).
- Tested material conditioned at 90 °F (32 °C), pucks conditioned at 90 °F (32 °C), and test material cured at 90 °F (32 °C).

Exceptions include:

- Hilti HIT Ice, which is a cold weather formulation, was only tested under one condition at 36 °F (2 °C).
- The two seam sealer products and a gasketing material were only tested under three conditions with material conditioned at room temperature.
- Bondo® and Splash Zone A788 were tested using a cold temperature of 59 °F (15 °C) instead of 36 °F (2 °C).

Pictures of the tested materials are mostly presented with both the carbon and stainless tested pucks in one picture. In these pictures, the carbon pucks are on the left and the stainless on the right.

3.5 Sealants tested

Numerous products were investigated for use in this application. The initial list of sealants was compiled based on results of the telephone survey of District experiences with contact blocks. This list included one-part sealants (silicone, urethane, urethane foam), two-part sealants that needed to be mixed in batches (Bondo®, Splash Zone, Belzona ceramic metal), and a two-part anchor grout applied via dual caulk tubes and a mixing nozzle. Only one product (Splash Zone) was marketed for sealing or patching steel in marine environments, including underwater application. Belzona is often applied in the dry to surfaces underwater during operation. Note that most of these materials are marketed for use(s) much different than addressed in this report and it is unlikely any of the manufacturers and retailers have ever considered such a use. Results in these tests do not indicate their expected performance for the intended purpose(s). Table 3-1 lists the products used to seal one or more test frames.

Table 3-1. Products used to seal test frames.

Sealant	Type	Results
Promising Test Results		
Liquid Roc 300 Twin Tube	Polyester	Very good results. Good strength, good adhesion to steel, easy to use, usable over a large temperature range. Good working time and cures relatively quickly.
Hilti HIT RE500	Epoxy	Very good results. Good strength, good adhesion to steel, easy to use, usable over a large temperature range. Good working time, but slower cure at lower temperatures.
Loctite Fixmaster® Anchor Bolt Grout HP	Epoxy	Very good results. Good strength, good adhesion to steel, easy to use, usable over a large temperature range. Good working time, but slower cure at lower temperatures.
WR Meadows POLY—GRIP	Polyester	Very good results. Good strength, good adhesion to steel, easy to use, usable over a large temperature range. Two tubes of material used failed to cure.
Bondo®	Polyester	Very good. Time consuming to mix and short working time. Adhesion to steel is very good. Not recommended at temperature below 55 °F (13 °C).
Splash Zone A—788		Very good. It is time consuming to mix, but working life is extremely long. Good in wet environments. Adhesion to steel is good. Tensile strength is less than most other promising materials. Not recommended at temperature below 50 °F (10 °C).
WR Meadows Rezi—weld	Epoxy	Very good, but application temperature range is very limited.

Sealant	Type	Results
Uncertain Test Results		
3M™ Factory—Match Seam Sealer, 200 mL, 08323	Polyurethane	Good results, but uncertain properties when applied at varied temperatures. Some tubes of material had material that did not set. More elasticity than the grouts and adhesives.
3M™ Heavy—Bodied Seam Sealer, 200 mL, 08308	Polyurethane	Good results, but uncertain properties when applied at varied temperatures. Adhesion not quite as good as 08323 seam sealer. More elasticity than the grouts and adhesives.
Loctite 5607 Silicone Adhesive	Silicone	Good results, but uncertain properties when applied at varied temperatures. Material is much weaker than other promising materials, but adhesion to steel was good and it is very elastic.
Unfavorable Test Results		
Redhead A7	Acrylic	Poor adhesion at colder temperatures. Short working time at warmer temperatures.
Hilti HIT—HY 10 Plus	Urethane Methacrylate	Poor adhesion at colder temperatures. Short working time at warmer temperatures.
Hilti HIT—HY 200R	Urethane Methacrylate	Poor adhesion at colder temperatures. Low viscosity at warmer temperatures.
Hilti HIT ICE	Epoxy Acrylate	It is primarily a cold weather product that had poor adhesion to steel at lower temperatures.
Five Star HP Anchor grout	Epoxy Acrylate	Poor adhesion to steel.
Redhead G5	Epoxy	Limited temperature range. At the low end it was difficult to apply. At higher temperatures it had low viscosity.
Hilti Foam CF—ASCJP	Polyurethane	Could not get a tight seal.
Touch ’n Seal All Season Polyurethane Foam	Polyurethane	Could not get a tight seal.
One part silicone caulk	Silicone	Long cure time and weak adhesion to steel.
One part polyurethane caulk	Polyurethane	Long cure time and weak adhesion to steel.
3M™ Scotch—Weld™ Epoxy Adhesive DP420	Acrylic	Low viscosity. It would not hold position.

Initial testing focused on anchor grouts from one manufacturer and one-part sealants. While the one-part caulks did not cure as quickly as desired, the anchor grouts gave promising results. It was decided that further testing should focus on anchor grouts and other two-part tube applied products. Additional products of this type from other manufacturers were obtained for testing. These nozzle-mixed products have varying temperature-dependent cure rates and ranges. There was no nozzle adjustment to change the mix ratio and adjust for temperature. Two brands of applicator-applied canned polyurethane foam were also obtained for testing. All materials tested at multiple temperatures had less favorable results at low temperatures.

3.6 Liquid Roc 300 twin tube

3.6.1 Description

LiquidRoc 300 is a polyester-based anchor grout available in a 28 oz, two-component, 10:1 mix cartridge. It can be used in damp conditions or underwater. It is recommended for use in temperatures from 25 to 100 °F (-4 to 38 °C). The cure time should be fast enough at lower temperatures (Table 3-2) for the contact block application.

A similar product by the same manufacturer, LiquidRoc 500, is designed for use in temperatures from 40 to 100 °F (4 to 38 °C) and may also have acceptable properties. The strong odor from the uncured material suggests that breathing protection may be desirable. Further information is available at: http://www.mktfastening.com/

Table 3-2. Cure time for LiquidRoc 300 polyester-based anchor grout

Concrete Temperature		Time
Over 80 °F	(Over 27 °C)	20-30 min.
80 to 68 °F	(27 to 20 °C)	30 to 40 min.
68 to 58 °F	(20 to 14 °C)	40 to 50 min.
58 to 48 °F	(14 to 9 °C)	1 hr
48 to 38 °F	(9 to 3 °C)	2 hrs
38 to 28 °F	(3 to -2 °C)	4 hrs

3.6.2 Mock quoin block test

Liquid Roc 300 was tested at 75 °F (24 °C). The first test of working time missed the gel period because the bead gelled irregularly. In other words, material that extruded later, gelled sooner. A second test was run and the material gelled in 13 to 14 minutes (Figure 3-6). Given the cure time, this was unexpectedly long.

The performance of the cured material was similar to that of the A7 and Polygrip (i.e., it was exceptionally good). Liquid Roc 300 and Polygrip are both polyester-based so their similar performance is not surprising. After the pressure test, the seal was broken by tightening the push bolts (Figure 3-7). This took substantial wrench torque and actually broke the material bead through the center. It did not separate at the steel surface. Cleanup of the steel plates was difficult due to the strong adhesion to the surface.

3.6.3 Discussion

Subjectively, this material appeared to perform best although one test puck failed before it could be tested and one or two had rather low tensile strengths. Testing indicates this material is adequate for this application.

Figure 3-6. Test of Liquid Roc 300.

Figure 3-7. Breaking the Liquid Roc 300 seal.

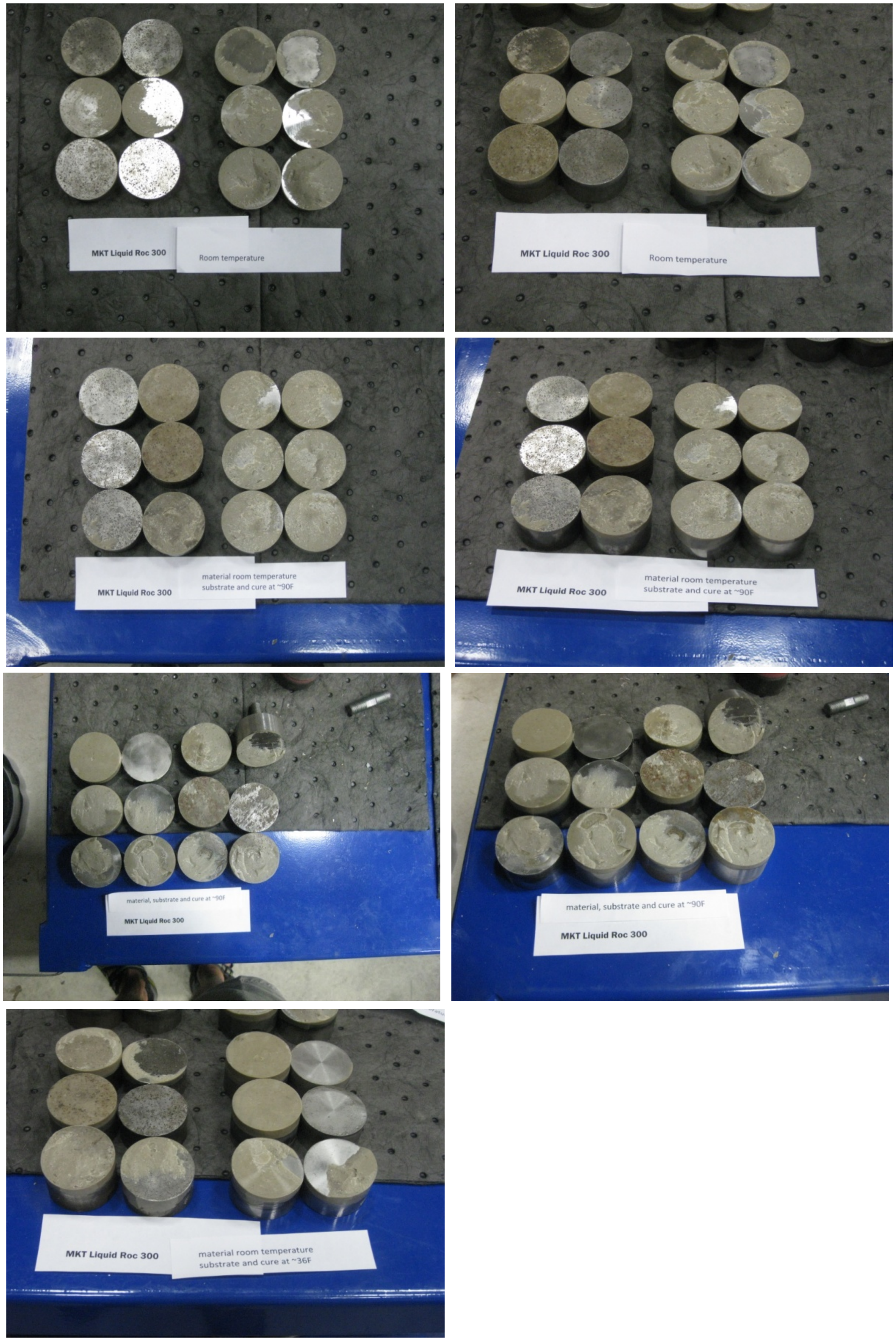
3.6.1 Tensile Tests

This material performed well in tensile testing except for one puck that did not bond (Table 3-3 and Figure 3-8).

Table 3-3. Tensile test results for Liquid Roc 300 twin tube.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
75 °F (24 °C)	75 °F (24 °C)	Carbon steel	398	254
75 °F (24 °C)	75 °F (24 °C)	Stainless Steel	895	274
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	408	704
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	1756	854
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	600	316
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	861	10
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	432	216
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	178	228
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	247	214
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	373	236

Figure 3-8. Pucks after tensile tests for Liquid Roc 300 twin tube.



3.7 Hilti HIT RE500

3.7.1 Description

The HIT RE500 system is a low odor, epoxy anchor grout available in a 500 mL, two-component, 5:1 mix cartridge. It is specifically designed for fastening into concrete, grout, stone, or masonry. It is recommended for use in temperatures from 23 to 104 °F (-5 to 40 °C) (Table 3-4). The gel time should be adequate at the highest temperatures, but the cure time may be longer than desired for contact block applications, especially at lower temperatures (Table 3-5). Further information is available at: https://www.us.hilti.com/anchor-systems/injectable-adhesive-anchors/r1216

Table 3-4. Full cure times (100% of working load) for HIT RE500 epoxy anchor grout.

Base Material Temperature	Approximate Full Curing Time (hrs)
23 °F (–5 °C)	72 hrs
32 °F (0 °C)	50 hrs
50 °F (10 °C)	24 hrs
68 °F (20 °C)	12 hrs
86 °F (30 °C)	8 hrs
104 °F (40 °C)	4 hrs

Table 3-5. Gel timetable (approximate) for HIT RE500 epoxy anchor grout.

Base Material Temperature	Approximate Gel Time (hrs)
23 °F (–5 °C)	4 hrs
32 °F (0 °C)	3 hrs
50 °F (10 °C)	2 hrs
68 °F (20 °C)	30 min
86 °F (30 °C)	20 min
104 °F (40 °C)	12 min

3.7.2 Mock quoin block test (first)

When applied at room temperature, the Hilti HIT RE500 material was the consistency of pudding or yogurt, just barely stiff enough so it did not run. Caulking on the underside of the plates did result in some drippage, but it was not difficult to apply (Figures 3-9 and 3-10). Application at higher temperatures needs to be demonstrated to verify it will hold in place until gelled.

Figure 3-9. Setup for testing of Hilti HIT RE500 on steel plates.

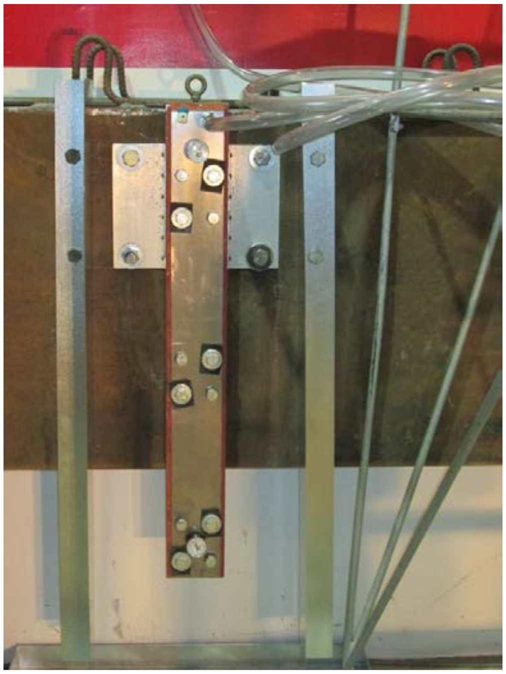
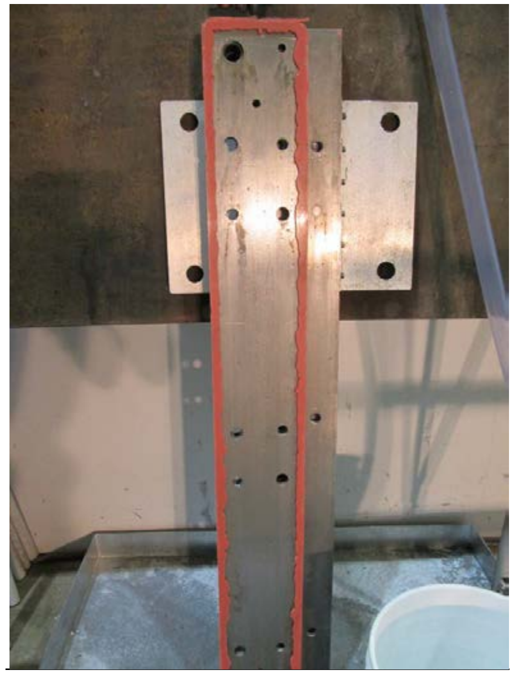


Figure 3-10. Application of Hilti HIT RE500 to steel plate.



The Hilti catalog lists a gel time of 30 minutes at 68 °F (20 °C). During CERL testing at 80 °F (27 °C), the gel time was over 60 minutes. At 80 minutes, the product began to stiffen and become more viscous, but the transition seemed slow compared to 200R and HIT ICE. Hilti HIT RE500 was relatively easy to work compared to the other Hilti products. The material was easy to apply and produced a good seal. Its light color and texture made it easy to visually inspect the seal for completeness. The proof test of the seal was successful. Full water head was applied and successfully held.

This product has a long cure time at temperatures below 50°F (10 °C). There are also concerns about its potential for sag at temperatures above 80 °F (27 °C). This will be tested.

3.7.3 Mock quoin block test (second)

Hilti HIT RE500 was previously tested at 80 °F (27 °C). A concern developed whether this sealer would sag at higher temperatures. A second test was performed at 94 °F (34 °C). The material did not sag while being applied. It appears that high outdoor temperatures are not a problem when applying this material. The working time is sufficiently long. Above 86 °F

(30 °C), the cure time is less than 8 hours. This product can also be used down to 23 °F (-5 °C), but the cure time rises as high as 3 days at the lowest temperature.

The proof test of the seal was successful. Full water head was applied and successfully held.

3.7.4 Tensile tests

This material performed well in tensile testing (Table 3-6 and Figure 3-11).

3.7.5 Discussion

Hilti HIT RE500 had some of the highest tensile strengths of any material. Although this material is recommended for use down to 23 °F (-5 °C), there was a noticeable reduction in strength at lower temperatures. Cure times also increase substantially at lower temperatures. This material is recommended for the application.

Table 3-6. Tensile test results for Hilti HIT RE500.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
75 °F (24 °C)	75 °F (24 °C)	Carbon steel	1589	1
75 °F (24 °C)	75 °F (24 °C)	Stainless Steel	2088	446
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	1976	247
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	1274	454
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	942	577
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	899	76
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	522	119
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	479	43
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	224	50
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	217	41

Figure 3-11. Pucks after tensile tests for Hilti HIT RE500.

3.8 Loctite Fixmaster® Anchor Bolt Grout HP

3.8.1 Description

Fixmaster® HP is a solvent-free, no-odor anchor grout formulated to anchor threaded rods, bolts, rebar dowels, and smooth dowels into concrete, grout filled block, and masonry. It is available in a 28 oz, two-component, 1:1 mix cartridge. It is recommended for use in temperatures from 36 to 115 °F (2 to 46 °C). Mixed working time is listed as 20 minutes at 77 °F (25 °C). The cure time of 3 to 24 hrs, depending on temperature, should be fast enough at lower temperatures (Figure 3-12) for the contact block application. Further information is available at:
http://www.henkelna.com/industrial/loctite-fixmaster-anchor-bolt-grouts-7052.htm

3.8.2 Mock quoin block test

Loctite Fixmaster HP anchor grout flowed easily out of the nozzle, forming a good bead that could be rather easily worked into place. It was somewhat difficult to get grout to stay in place on the short underside of the test setup, but the task could be successfully completed. Overall ease of application was very good. One concern was that, on returning to the test setup about 15 minutes after caulking the gaps, a significant amount of the grout had sagged, run down the side, and dripped to the floor (Figures 3-13 and 3-14). The seal appeared to still be in place, but the thickness was obviously reduced in places. The length of the nozzle was a slight inconvenience, but when working from a man-basket or bucket, the extra length might turn out to be an advantage. The proof test of the seal was successful. Full water head was applied and left in place over the weekend.

Figure 3-12. Cure time for Fixmaster HP anchor grout.

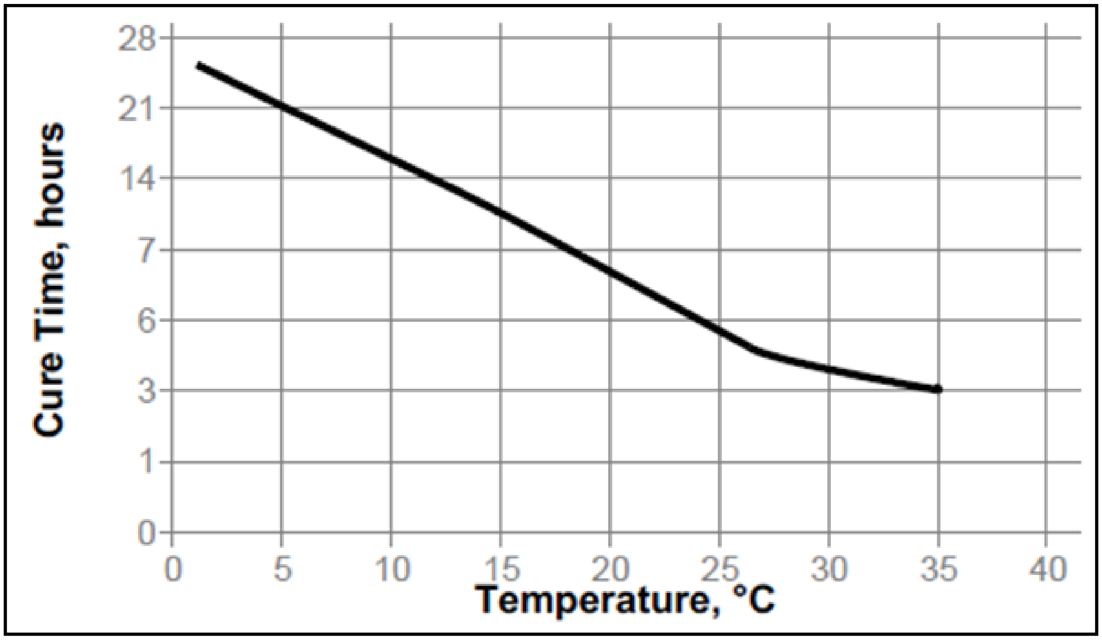


Figure 3-13. Loctite Fixmaster HP anchor grout dripping off application site.

Figure 3-14. Loctite Fixmaster HP anchor grout application beginning to run.

The Loctite literature lists a working time of 20 minutes at 77 °F (25 °C). During CERL testing at 90 °F (32 °C), a test bead started to thicken slightly after 12 minutes. At 18 to 22 minutes, it had not yet gelled, but had stiffened further and was more difficult to work due to forming a "string" between the caulk bead and the tool as the tool was removed.

3.8.3 Tensile tests

This material performed well in tensile testing (Table 3-7 and Figure 3-15). The lower strengths at 75/36 °F (24/2 °C) temperatures were due to the material not being fully cured.

3.8.4 Discussion

Loctite Fixmaster HP had marginally adequate viscosity in the mock quoin block test. It was not fully set after 24 hours in the 75/36 °F (24/2 °C) testing. Testing indicates this material is adequate for this application.

Table 3-7. Tensile test results for Loctite Fixmaster® Anchor Bolt Grout HP.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	691	151
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	1088	114
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	810	109
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	480	137
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	614	134
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	455	85
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	119	12
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	97	51
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	206	50
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	457	92

Figure 3-15. Pucks after tensile tests for Loctite Fixmaster® Anchor Bolt Grout HP.

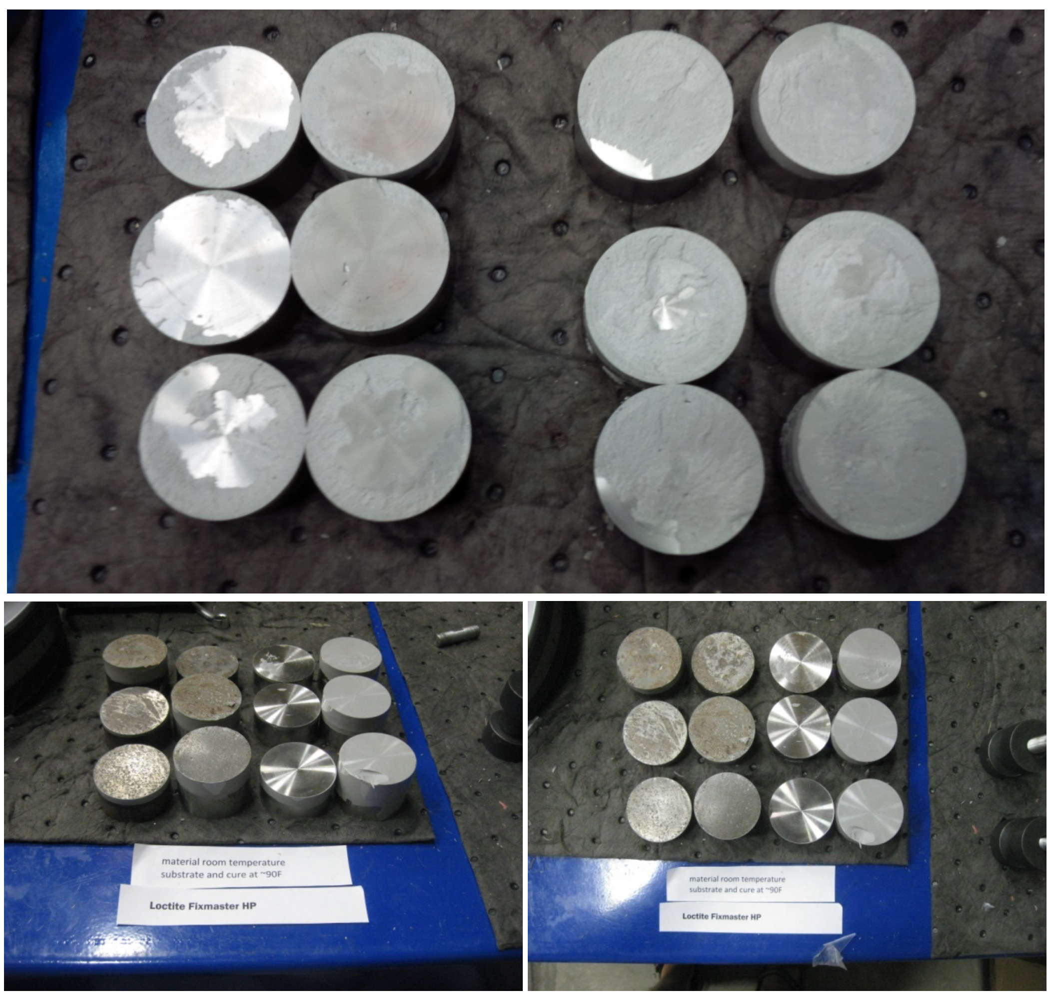


Figure 3-15. (Cont'd.).

Not fully cured

Substrate, material and cure at 36 °F (2 °C)

3.9 WR Meadows Polygrip

3.9.1 Description

Polygrip is a polyester-based anchor grout available in a 28 oz two-component, 10:1 mix cartridge. It requires a dry surface. It is recommended to apply this product in temperatures from 25 to 120 °F (-4 to 49 °C). Given the application of concern, the working time is a little short at higher temperatures, although the cure time should be fast enough at lower temperatures (Table 3-8). The strong odor from the uncured material suggests that breathing protection may be desirable. Further information is available at: http://www.wrmeadows.com/poly-grip-anchoring-adhesive

3.9.2 Mock quoin block test

W.R. Meadows Polygrip was tested at 81 °F (27 °C). A test bead was found to be workable for 5 minutes. By 6 minutes, the material had become too firm to work. It very quickly transformed from completely workable to difficult or impossible to work. Still, the material seemed to adhere and the seal looked good (Figure 3-16).

While the working time was a bit shorter than desired at the tested temperature of 80 °F (27 °C), in the end the result was an exceptionally good seal. After the pressure test, the seal was broken by tightening the push bolts. This took substantial wrench torque and actually broke the material bead through the center. It did not separate at the steel surface. Cleanup of the steel plates was difficult due to the strong adhesion to the surface.

Table 3-8. Load table for Polygrip polyester-based anchor grout.

Temperature*		Working Time	Load Time
85 °F	(29 °C)	5.5 min	35 min
78 °F	(26 °C)	7 min	55 min
45 °F	(7 °C)	35.5 min	90 min
35 °F	(2 °C)	90 min	240 min

* Recommended temperatures between 2 and 120 °F (–3.9 to –48.9 °C).
Warming of cartridge may be necessary when using below 40 °F (4 °C).

Figure 3-16. Test of W.R. Meadows Polygrip.

3.9.3 Tensile tests

This material performed well (Table 3-9) in tensile testing except for two tubes of material that did not set.

Table 3-9. Tensile test results for WR Meadows Polygrip.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	315	246
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	265	270
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	373	236

3.9.4 Discussion

Due to difficulties obtaining this material, most of the tensile tests could not be run until near the end of project funding. For uncertain reasons, many of these samples did not set and could not be tested. Nonetheless, it is expected this was anomalous and not indicative of how this material would generally perform. Other tests all resulted in satisfactory results.

3.10 Bondo®

3.10.1 Description

Bondo® is a two-part commercial polyester filler most typically used in auto body repair work. It can be mixed in small batches and applied to small areas. It sets quickly and can be sanded and painted. According to the manufacturer, full cure is not reached until 24 hours after mixing. Bondo® can be applied at temperatures up to 165 °F (74 °C). The manufacturer recommends this product not be applied at temperatures below 55 °F (13 °C).

3.10.2 Mock quoin block test

When products for testing were first obtained, three were two-component products that required hand mixing. Hand-mixed products have both advantages and disadvantages. The primary advantage is that the mixture ratio can be easily adjusted based on conditions. One disadvantage is that the applicator must have the expertise to appropriately adjust the mixture ratio without resulting in a poorly performing mixture. A second disadvantage is that the hand-mixing process requires time and effort to hand-mix the products by batch. It was decided early in this research to focus on nozzle-mixed, two-component products. Bondo® was tested as a control. Since most miter gate contact blocks are currently being installed using Bondo® as the backing material cavity sealant, it was important to test the use of this product.

Application to the mock contact blocks was completed without difficulty under controlled laboratory conditions with a temperature of 78 °F (26 °C). Each mixed batches covered 2-3 ft of the perimeter. It is likely that larger batches could be mixed and applied without difficulty. Because the laboratory applicators had limited experience, conservative practices were used. Although it did take significantly longer to seal the blocks than when using nozzle mixed products, the results were good. The material performed satisfactorily in the pressure test.

3.10.3 Tensile tests

This material performed well in tensile testing (Table 3-10 and Figure 3-17).

Table 3-10. Tensile test results for Bondo®.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70–75 °F (21–24 °C)	70–75 °F (21–24 °C)	Carbon steel	315	246
70–75 °F (21–24 °C)	70–75 °F (21–24 °C)	Stainless Steel	265	270
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	603	100
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	556	231
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	546	257
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	667	128
75 °F (24 °C)	59 °F (15 °C)	Carbon steel	627	265
75 °F (24 °C)	59 °F (15 °C)	Stainless Steel	502	213
59 °F (15 °C)	59 °F (15 °C)	Carbon steel	503	21
59 °F (15 °C)	59 °F (15 °C)	Stainless Steel	351	222

Figure 3-17. Pucks after tensile tests for Bondo®.

Figure 3-17. (Cont'd).

3.10.4 Discussion

Bondo® appears to be a satisfactory material for this application, but it has distinct advantages and disadvantages. It is more time consuming to mix and apply than the two-part epoxy cartridge applied materials. Also, Bondo® has a relatively short working time, which decreases at higher temperatures.

3.11 Splash Zone A-788

3.11.1 Description

Splash Zone A-788 is designed to be water resistant for patching and sealing in wet environments. It is a two-part epoxy compound that comes in two, 473 mL cans. It should be mixed by hand with a 1:1 ratio and then applied to the work surface. It was chosen because of its tolerance of a wet environment.

The work time for this product is listed at 40 minutes for a golf ball size sample at 70 °F (21 °C). This time is cut in half when the temperature is increased to 80 °F (27 °C). Material does not cure at temperatures below 50 °F (10 °C). While applying, Splash Zone A-788 has a clay-like texture so it is harder to work than most other materials, but stays in place very well.

Table 3-11. Product Information for Splash Zone A-788.

Item	Value
Product Code	8478800\1
Color Part A	Yellow
Color Part B	Black
Color Mixture	Olive Green
Work Time	Golf Ball Size: 40 min
Cure Time	6 to 8 hours
Manufacture	Pettit Paint
Size	473mL (16 FL. OZ.)

3.11.2 Mock quoin block test

This product is hand-mixed with equal parts of two components in amounts up to the equivalent of baseball size. Handling the material is done with wet hands to minimize sticking. The material is similar in consistency to clay. For this testing, batches were mixed in amounts similar to golfball size or slightly larger. To get it mixed, the required exertion and time is nearly double what might be expected for Bondo®.

Application of the mixed material to seal the perimeter was accomplished by forming the material into a “rope,” placing the rope, and then working it into the joint. Using this method, it was easy to form a continuous seal. The material performed satisfactorily in the pressure test.

3.11.3 Tensile tests

This material performed well in tensile testing (Figure 3-12 and Figure 3-18).

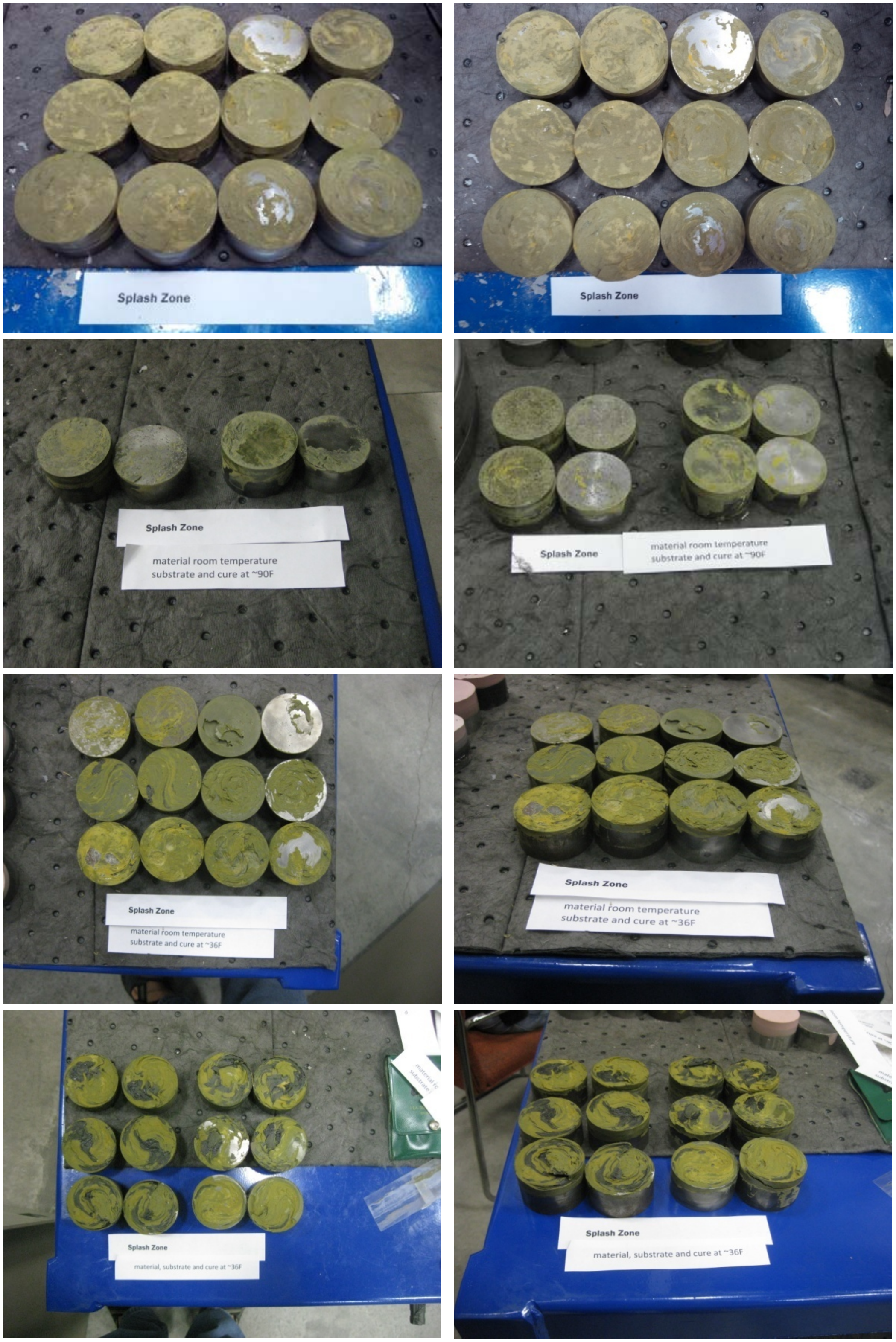
3.11.4 Discussion

Splash Zone A788 appears to be a satisfactory material for this application, but like Bondo®, it is more time consuming to mix and apply than the two-part epoxy cartridge applied materials. It is actually more time consuming to mix than Bondo®, but has the advantage of a much longer working time. It is also a good material for use in wet environments. It can be applied underwater. The material is not as strong as Bondo®, but like Bondo® it adheres well to the steel. As can be seen in Figures (lower-right illustration in Figure 3-18), care must be taken to ensure that the two parts are thoroughly mixed.

Table 3-12. Tensile test results for Splash Zone A-788.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
75 °F (24 °C)	75 °F (24 °C)	Carbon steel	190	35
75 °F (24 °C)	75 °F (24 °C)	Stainless Steel	233	36
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	336	70
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	324	79
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	342	113
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	271	106
75 °F (24 °C)	59 °F (15 °C)	Carbon steel	53	19
75 °F (24 °C)	59 °F (15 °C)	Stainless Steel	110	59
36 °F (2 °C)	59 °F (15 °C)	Carbon steel	59	12
36 °F (2 °C)	59 °F (15 °C)	Stainless Steel	57	9

Figure 3-18. Pucks after tensile tests for Splash Zone A-788.



3.12 WR Meadows Rezi-Weld Gel Paste State

3.12.1 Description

W.R. Meadows Rezi-Weld Gel Paste State is a construction epoxy meant for anchoring, bonding, and sealing. It is a two part epoxy with a 1:1 mixing ratio that comes in a 627 mL dual tube package. It is not affected by moisture once it is cured.

Rezi-Weld has a work time of 14-20 minutes and will cure after 4 hours at 75 °F (24 °C) (Table 3-13). The recommended application temperature is between 60 and 85 °F (29 and 16°C). Once cured it is a hard grey material. Further information is available at the manufacturer's website: http://www.wrmeadows.com/rezi-weld-gel-paste-state-construction-epoxy/

3.12.2 Mock quoin block test

Manufacturer literature lists a working time at 75 °F (24 °C) of 14–20 minutes. The test was performed at 76 °F (24 °C) and there was no difficulty with adequate time to apply the material and tool it into place.

When extruded into place, there were no noticeable issues with sag and it stayed in place before and after tooling. The seal held the water head overnight. When disassembling the plates, it was very difficult to break the seal, indicating very good adhesive properties on the slightly rusty and dirty steel.

Table 3-13. Product Information for W.R. Meadows Rezi-Weld™ Gel Paste State.

Item	Value
Manufactures No.	391–S
Case quantity	12
Color A/B	White/Black
Color mixture	Grey
Work time	14—20 min
Cure time	4 hours at 75 °F (24 °C)
Brand	W.R. Meadows
Size	627mL (21.2 fl. oz.)

3.12.3 Tensile tests

Because the material is not recommended for application beyond the temperature of 60 °F (16 °C) and 85 °F (29 °C), it was decided not to further test this material. Note that the results at room temperature were very good (Table 3-14 and Figure 3-19).

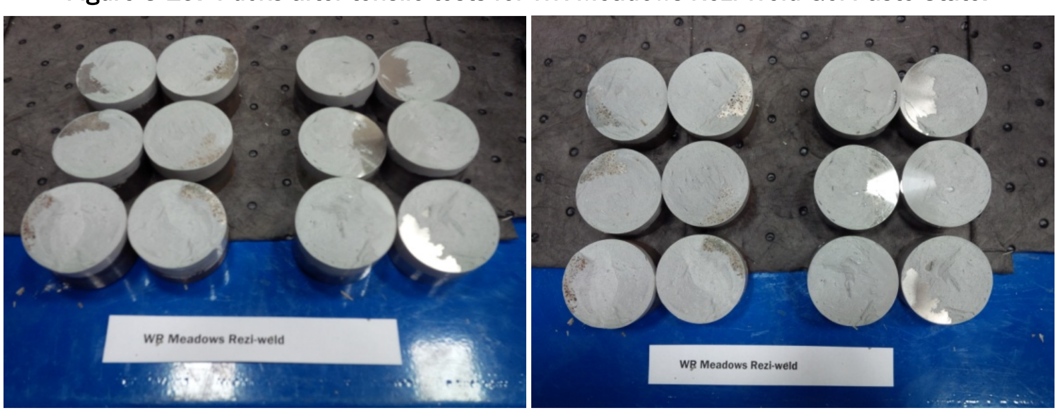
3.12.4 Discussion

Rezi-Weld performed well in both the mock quoin block test and the tensile tests at room temperature. Due to the limited application temperatures of between 60–85 °F (16–29 °C), further testing was not performed.

Table 3-14. Tensile test results for WR Meadows Rezi-Weld Gel Paste State.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	1188	56
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	784	117
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	–	–

Figure 3-19. Pucks after tensile tests for WR Meadows Rezi-Weld Gel Paste State.



3.13 3M™ Factory-Match Seam Sealer, 08323

3.13.1 Description

The 3M™ Factory-Match 08323 seam sealer is formulated for automotive seam repairs. It comes in 200 mL, two-component cartridges with 1:1 mix ratio formulated for adhesion to primed surfaces. This particular seam sealer was selected for its work time, drying time, and viscosity.

Another product by the same manufacturer, the 3M Factory-Match 08308, may also have acceptable properties. This low odor, heavy-bodied version also comes in a 600 mL cartridge.

A third 3M product, the Factory-Match 08310 Bare Metal Seam Sealer, may have even better adhesion properties and non-sag properties, but with slightly less working time.

The manufacturer lists no temperature-based properties for any of these products. Because this product is intended for use in controlled environments, the manufacturer's literature lists no additional information on working, gel, cure, or load times at other temperatures (Table 3-15). Further information is available at:
http://3mcollision.com/products/sealants/3m-factory-match-seam-sealer-08323.html#moreInfoDetails

Table 3-15. Product information for 3M™ Factory-Match Seam Sealer, 08323.

Item	Value
3M Part No.	08323
UPC	51135083239
Case quantity	6 cartridges per case
Case inner pack	1 cartridge
Color	Black
Paint time	30 min
Work time	10-15 min
Dry time	30 min
Brand	3M
Size	200 mL (6.7 oz.)

3.13.2 Mock quoin block test (first)

The 3M™ Factory-Match literature lists a working time of 10 to 15 minutes, but does not mention temperature. During CERL testing at 76 °F (24 °C), a test bead was found to be workable for about 13 minutes and definitely not workable beyond 14 minutes. When the material came out of the nozzle, it had a very liquid quality (flowed easily), but started to firm very quickly. Within 5 seconds, it no longer sagged. Unlike other materials that maintained relatively stable viscosities during the working life, the viscosity of this product continuously increased. After 9 to 10 minutes, concern began to develop regarding workability of a test bead because the material was increasingly stringy when a tool or gloved finger was worked into and removed from the material. This gradual hardening and increasing stringiness continued until at least 13 minutes. By 14 minutes, the material was not workable. After 5 minutes without use, the nozzle still flowed. After a separate 8-minute period, it was difficult (but still possible) to get the nozzle flowing again.

This material was stronger and less elastic than the two-part silicone caulk, but was not at all brittle like the epoxy grouts. It appeared to form a very good seal. It was relatively easy to visually verify that the surface of the black material completely covered the gap being sealed. On testing, this was indeed the case. The seal held the water head overnight. When disassembling the plates, it was very difficult to break the seal, indicating very good adhesive properties on the slightly rusty and dirty steel. The entire caulk bead applied to the plates removed in one piece.

3.13.3 Quoin block test (second)

This was the second test of the seam sealer material and the first test performed using the c-channel and stainless steel miter block. This test was done at 94 °F (34 °C). The material may have been slightly less viscous on first application than the previous test at lower temperature, but it began firming up quickly and held position adequately (Figure 3-20). A test strip stayed workable for about 8 minutes and was unworkable after 9 minutes.

The nozzle was nearly clogged after 7 minutes, but a couple pumps of pressure opened it. Note that earlier, a nozzle that had been used for more than a full tube was left sitting for an undetermined long period and the subsequent application had visibly separated material (Figure 3-21). It is not clear if this was due to how long the material had sat in the nozzle, to the length of time the nozzle had been in use, or some combination of the two.

Figure 3-20. Application of 3M™ Factory-Match (automotive) seam sealer.

Figure 3-21. Material separation of application of 3M™ Factory-Match (automotive) seam sealer.

The proof test was not acceptable. Once disassembled, it was found that most of the material had set and had very good strength, but in numerous locations, the material was soft and sticky. Even months later, these locations did not set. Because the test sample was so big, and the seam sealer tubes are very small relative to other products tested, many tubes were used and the locations of the soft areas would clearly be from different tubes. Because one nozzle was used, it is possible that the nozzle was defective, that material had set in the nozzle, that the high temperature affected the material, or that some other unidentified variable affected the material's performance.

3.13.4 Tensile tests

This material performed well in tensile testing at room temperature (Table 3-16 and Figure 3-22).

Table 3-16. Tensile test results for 3M™ Factory-Match Seam Sealer, 08323.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	389	76
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	309	99
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	–	–

Figure 3-22. Pucks after tensile tests for 3M™ Factory-Match Seam Sealer, 08323.

3.13.5 Discussion

Seam sealer 08323 is intended for automotive use. Based on the manufacturer literature, it appears to be intended for application at room temperature. Because the material is intended for application at room temperature, only limited tests were made using this material. The material is stronger than the bond to the steel. It is more elastic than the grouts and adhesives, but not as elastic as Loctite 5607.

3.14 3M Heavy Bodied Seam Sealer (08308)

3.14.1 Description

3M™ Heavy-Bodied Seam Sealer is designed for sealing gaps or joints on painted metals. It is a two part epoxy that comes in a 200 mL, two-component cartridge that mixes with a 1:1 ratio. This product was selected because of its low work time and its non-sag property, which makes it easy to apply vertically. It has a work time of 6 minutes and will cure in 1 hour (Table 3-17). Once dry, it is a flexible rubbery material.

3.14.2 Mock quoin block test

This material performed very similar to the Factory Match seam sealer. It was slightly more viscous coming out of the cartridge, but did not gradually harden to as great of an extent. It did not sag.

Once cured, its performance was very similar to the Factory Match seam sealer

Table 3-17. Product information for 3M™Heavy-Bodied Seam Sealer, 08308.

Item	Value
3M™ Part No.	08308
UPC	51131168089
Case quantity	6
Case inner pack	1 cartridge
Color	Black/White
Paint time	15 min
Work time	6 min
Cure time	1 hour
Brand	3M
Size	200mL (6.75 fl. oz.)

3.14.3 Tensile tests

This material performed well in tensile testing at room temperature (Table 3-18 and Figure 3-23).

3.14.4 Discussion

Seam sealer 08308 is intended for automotive use. Based on the manufacturer literature, it appears to be intended for application at room temperature. The material is similar to the 08323 seam sealer, which had better adhesion in the tensile tests performed. The material is stronger than the bond to the steel. It is more elastic than the grouts and adhesives, but not as elastic as Loctite 5607.

Table 3-18. Tensile test results for 3M Heavy Bodied Seam Sealer (08308).

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	201	11
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	124	30
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	–	–

Figure 3-23. Pucks after tensile tests for 3M Heavy Bodied Seam Sealer (08308).

3.15 Loctite 5607 Silicone Adhesive

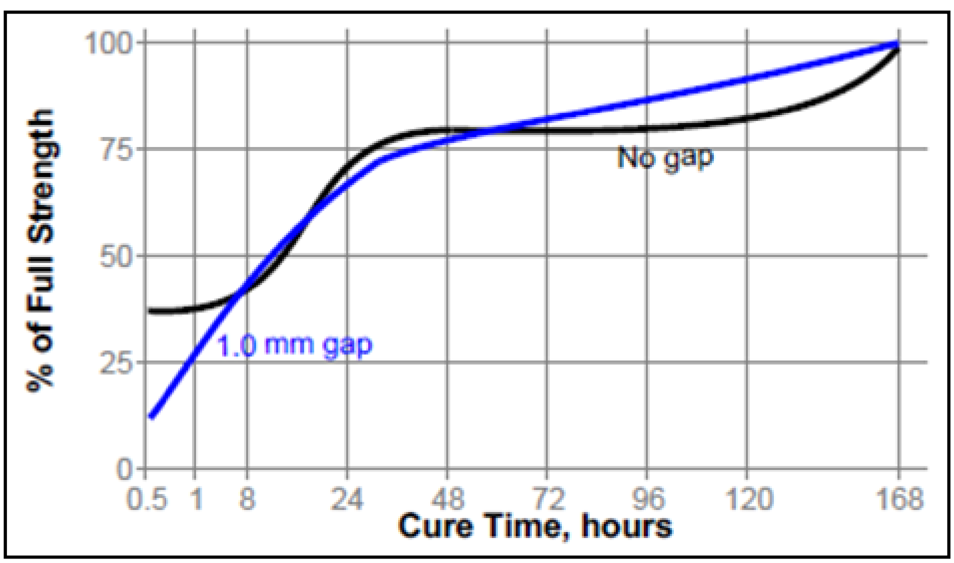
3.15.1 Description

Loctite 5607 is a low odor, silicone-based adhesive/sealant designed for form-in-place gasketing of electronic control modules. It is available in 400 mL, two-component cartridges with a 2:1 mix ratio. Loctite literature lists a fixture time on steel of 10 to 15 minutes at 77 °F (25 °C). An application temperature range is not stated. Strength attainment is provided based on a temperature of 72 °F (22 °C) (Figure 3-24). Further information is available at:
http://www.henkelna.com/product-search-1554.htm?nodeid=8797946052609

3.15.2 Mock quoin block test

The Loctite 5607 silicone adhesive had a good working consistency, but the DM400 applicator that was used extruded only a small amount of material with each manual squeeze. This proved a bit tiring for the ~9 ft caulk line for the test specimen and would likely be a bigger concern when caulking an entire gate height. The initial proof test immediately failed at the center of the top caulk bead, indicating that the application might have been the problem. Before water head was removed, the caulk failed in two other places on a top corner. The top area was re-caulked and tested again. The second test was successful. Full water head was applied and left in place overnight. The water head held successfully.

Figure 3-24. Strength attainment for Loctite 5607 silicone-based adhesive based on a temperature of 72 °F (22 °C).



The Loctite literature lists a fixture time of 50 minutes with no stated adjustment for temperature. During CERL testing at 84 °F (29 °C), a test bead was workable after 13 minutes. At 16 minutes, it was very elastic (more elastic than after it had fully cured), but not workable. This material has less strength than the anchor grouts, but is much more elastic and has very good adhesion to the steel. When a putty knife was used to remove the adhesive from the steel, the knife cut the silicone instead of peeling it from the steel.

3.15.3 Tensile Tests

Because the material does not have a stated range of application temperatures, it was assumed that it was intended to be used at room temperature. Nonetheless, tests were performed with puck and cure temperatures at the warm and cool extremes. The tensile strength appears to be relatively low, but the adhesion was excellent and the material is extremely elastic – far more elastic than even the seam sealers (Table 3-19 and Figure 3-25).

3.15.4 Discussion

Loctite 5607 is material with a primary use in gasketing. Based on the manufacturer literature, it appears to be intended for application at room temperature. No information is provided for application or service at other temperatures. For this reason, all tests were run with the stock material at room temperature, but some tests were run with higher and lower cure temperatures. The material is relatively weak, but the adhesion to steel was good. Figure 3-26 shows that this material is very elastic and can undergo large deformations with breaking or losing adhesion.

Table 3-19. Tensile test results for 3M Loctite 5607 Silicone Adhesive.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	84	4
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	62	11
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	55	6
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	38	4
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	56	25
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	39	25
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	–	–

Figure 3-25. Pucks after tensile tests for Loctite 5607 Silicone Adhesive.

Figure 3-26. Loctite 5607 tensile elongation.

3.16 Redhead Epcon A7 Acrylic Adhesive

3.16.1 Description

Epcon A7 is an acrylic-based anchor grout available in 28 oz, two-component, 10:1 mix cartridges. The manufacturer's literature says it will work in damp and underwater applications. It is recommended for use in temperatures from 0 (zero) to 100 °F (-18 to 38 °C). Given the application of concern, the working time is a little short at higher temperatures although the cure time should be fast enough at lower temperatures (Table 3-20). The strong odor from the uncured material suggests that breathing protection may be desirable. Further information is available at:
http://www.itwredhead.com/product.php?A7-Acrylic-Adhesive-1

3.16.2 Mock quoin block test (first)

Note that, after completing this test, it was discovered that the material had expired 4 months before the test.

Table 3-20. Working and cure times for Epcon A7 Acrylic Adhesive.

Base Material		Working Time	Full Cure Time
100 °F	(38 °C)	5 min.	25 min.
80 °F	(27 °C)	5.5 min.	30 min.
60 °F	(16 °C)	7 min.	35 min.
40 °F	(4 °C)	15 min.	75 min.
20 °F	(–7 °C)	35 min.	6 hrs
0 °F	(–18 °C)	4 hrs	24 hrs

The manufacturer's information suggests that, for a non-standard use as a sealant, at room temperature or higher, Redhead Epcon A7 would probably gel more quickly than preferred. That was indeed the opinion of the applicator. The Redhead literature lists a working time of 5.5 minutes at 80 °F (27 °C). During CERL testing at 78 °F (26 °C), a test bead was workable until about 5 minutes. A skin was noticeable at about 4 minutes. The skin and the material continued to harden and were unworkable after about 5 minutes. The material is gritty, but seemed to adhere and the seal looked good (Figure 3-27). On testing, the seal was clearly inadequate. Many leaks occurred when water pressure was applied (Figure 3-28), mostly at the interface between the grout and the back plate.

When separating the test plates, it was found that there was almost no adhesion to the back plate. There was no "bounce" as the material released. It was hard to tell that it had released. One hypothesis is that the fine aggregate decreased surface contact and therefore reduced adhesion.

Figure 3-27. Application of Redhead Epcon A7 anchoring adhesive.

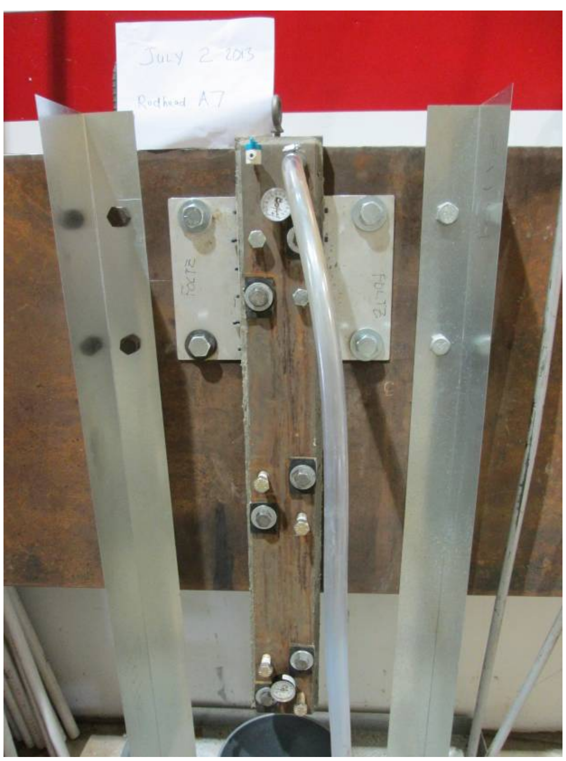


Figure 3-28. Leaks that appeared after applying water pressure to application of Redhead Epcon A7 anchoring adhesive.

Nevertheless, while other materials with fine aggregate also had marginal adhesion, Redhead A7 was generally better than other similar materials tested. One anomaly was that, although most of the Redhead A7 material showed poor adhesion, approximately 20% showed adhesion as good as or better than other materials with fine aggregate. It is possible that, if the material had been worked into the gap more thoroughly, the adhesion would have improved. Even if this were true, the uneven results suggest that this procedure is not dependable enough for use in the field.

Note that the working time was short enough to make application difficult (but not impossible, especially with a lot of nozzle changes). Normally, it would be advisable to avoid this product, but Redhead Epcon A7 may serve if a very short cure time were needed since it cures in less than 2 hours at temperatures above 40 °F (4 °C).

3.16.3 Mock quoin block test (second)

This second test of Redhead Epcon A7 anchoring adhesive was done at 80 °F (27 °C). A test bead was found to be workable for about 5 minutes. A skin was noticeable soon after 3 minutes. The skin and the material continued to harden and were unworkable at about 5 minutes or a little less. The material is gritty, but seemed to adhere and the seal looked good (Figure 3-29).

While the working time was a bit shorter than desired at the tested temperature of 80 °F (27 °C), in the end the result was a good seal. After the pressure test, the seal was broken by tightening the push bolts (Figure 3-30). This took substantial wrench torque and actually broke the material bead through the center. It did not separate at the steel surface. Cleanup of the steel plates was difficult due to the strong adhesion to the surface.

3.16.4 Tensile tests

This material performed well at temperature at or above room temperature (Table 3-21 and Figure 3-31). The Carbon steel result at 75/36 °F (24/2 °C) is not nearly as good as it appears as two of the three samples had a 0 (zero) PSI load. The poor performance at colder temperatures is a surprise given that the material is designed for anchoring steel in concrete at temperatures down to 0 °F (-18 °C).

Figure 3-29. Test of Redhead Epcon A7 anchoring adhesive.

Figure 3-30. Broken seal of Redhead Epcon A7 anchoring adhesive following the test.

Table 3-21. Tensile test results for Redhead Epcon A7 Acrylic Adhesive.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	629	337
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	715	71
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	505	436
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	384	431
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	622	283
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	615	284
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	217	375
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	0	0
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	1	2
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	0	0

Figure 3-31. Pucks after tensile tests for Redhead Epcon A7 Acrylic Adhesive.

Figure 3-31. (cont'd).

3.16.5 Discussion

At warm temperatures, the gel time for this product is shorter than desirable and at colder temperatures, the adhesion was not adequate. Epcon A7 is not recommended for this application.

3.17 Hilti HIT-HY 10 Plus

3.17.1 Description

HIT-HY 10 Plus is a low odor, epoxy anchor grout available in a 500 mL, two-component, 5:1 mix cartridge. It is recommended for use in temperatures from 30 to 104 °F (-1 to 40 °C). Given the application of concern, it would be difficult to use this product at typical summer temperatures due to the short gel time (Table 3-22). Further information is available at: https://www.us.hilti.com/anchor-systems/injectable-adhesive-anchors/r4901

Table 3-22. Gel / full cure times for HIT-HY 10 Plus epoxy anchor grout.

Base Material		t_{gel}	t_{cure}
32 °F	(0 °C)	10 min.	4 hrs
41 °F	(5 °C)	10 min.	2.5 hrs
50 °F	(10 °C)	8 min.	1.5 hrs
68 °F	(20 °C)	5 min.	45 min.
86 °F	(30 °C)	3 min.	30 min.
104 °F	(40 °C)	2 min	20 min.

3.17.2 Mock quoin block test

HY10 Plus is a two-component product that has relatively fast gel and cure times. An attempt to use it at room temperature was made to gain further insight. At 80 °F (27 °C), it was not difficult to apply and was of a good consistency for placing and working. A test bead was workable for approximately 4¾ minutes, and by 5 minutes, became unworkable. The material performed satisfactorily in the pressure test, but when disassembling the test setup, the adhesion to the steel did not seem particularly strong.

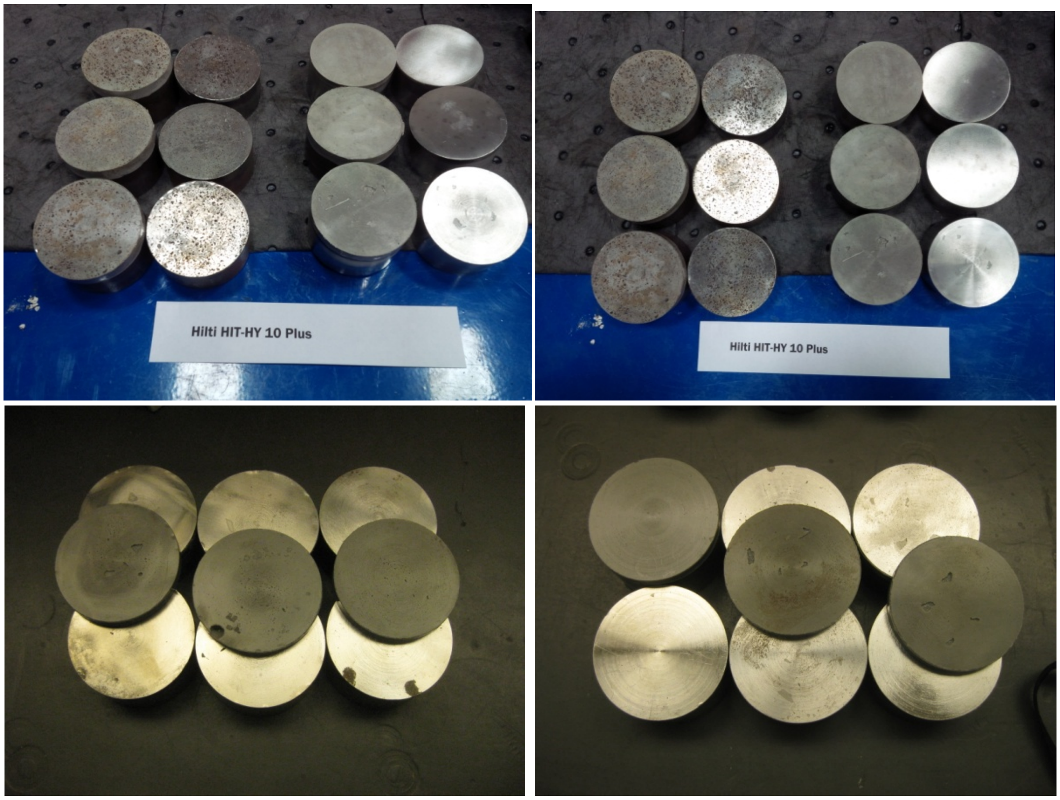
3.17.3 Tensile tests

While tensile tests of this material were satisfactory at room temperature, it did not adhere to the pucks at lower temperatures (Table 3-23 and Figure 3-32).

Table 3-23. Tensile test results for Hilti HIT-HY 10 Plus.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	135	27
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	103	34
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	0	0
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	0	0

Figure 3-32. Pucks after tensile tests for Hilti HIT-HY 10 Plus.



3.17.4 Discussion

At warm temperatures, the gel time for this product is far shorter than desirable and at colder temperatures, the adhesion was not adequate. HIT-HY 10 Plus is not recommended for this application.

3.18 Hilti HIT-HY 200R / HIT-HY 200A

3.18.1 Description

HIT-HY 200R is an epoxy anchoring system available in a 500 mL, two-component, 5:1 mix cartridge. It is recommended for use in temperatures from 14 to 104 °F (-10 to 40 °C). Given the application of concern, the gel time may be less than ideal at the highest temperatures. The same manufacturer makes a similar product, HIT-HY 200A, which has accelerated working and cure times (Table 3-24). Further information is available at: https://www.us.hilti.com/anchor-systems/injectable-adhesive-anchors/r4993

Table 3-24. Cure time for HIT-HY 200 epoxy anchor grout.

Base Material Temperature	HIT-HY 200-R Regular Working Time		HIT-HY 200-A (Accelerated Working Time)	
	Twork	tcure	twork	tcure
14 °F (−10 °C)	180 min.	20 hrs	90 min.	7 hrs.
23 °F (−5 °C)	180 min.	20 hrs	90 min.	7 hrs
32 °F (0 °C)	90 min.	7 hrs	50 min.	4 hrs
50 °F (10 °C)	40 min.	2 hrs	15 min.	1 hr
68 °F (20 °C)	15 min.	1 hr	7 min.	30 min.
86 °F (30 °C)	9 min.	1 hr	4 min.	30 min.
104 °F (40 °C)	6 min.	1 hr	3 min.	30 min.

3.18.2 Mock quoin block test

Hilti HIT-HY 200R contains fine aggregate, which resulted in some negative characteristics (in comparison with the HIT RE500) when used as a sealant. While field application on the contact blocks is unlikely to include underside work, this proved very difficult on the lab samples. The material did not sag much, but it was hard to get additional material to adhere, and also difficult to add to the sealer that had already been applied on the underside to build up enough thickness. Continued effort, by an admittedly inexperienced applicator, was not successful in creating a good seal on the underside. The texture and color (which gradually darkens as the product cures) were not optimal for visual verification. This product gelled much more quickly than the instructions indicated. It was workable for only about 5 minutes.

Note that while the working time is short enough to make application difficult it is not impossible, especially with numerous nozzle changes. Normally it would be advisable to avoid this product, but HIT-HY 200R may serve if a very short cure time were needed since it cures in less than 2 hours at temperatures above 50 °F (10 °C).

3.18.3 Tensile tests

While tensile tests of this material were satisfactory at room temperature, it did not adhere to the pucks at lower temperatures (Table 3-25 and Figure 3-33). Since the material was difficult to use at room temperature due to low viscosity, further testing at room temperature and above was not performed.

Table 3-25. Tensile test results for Hilti HIT-HY 200R / HIT-HY 200A.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	185	55
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	59	45
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	0	0
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	0	0

Figure 3-33. Pucks after tensile tests for Hilti HIT-HY 200R / HIT-HY 200A.

3.18.4 Discussion

At warm temperatures, the gel time for this product was shorter than desirable and it was more difficult to tool this material than some other materials. At colder temperatures, the adhesion was not adequate. HIT-HY 200R is not recommended for this application.

3.19 Hilti HIT ICE

3.19.1 Description

HIT ICE is an epoxy acrylate anchor grout available in a 297 mL, two-component cartridge. It is recommended for use in temperatures from -10 to 90 °F (-23 to 32 °C). Given the application of concern, it would be difficult to use this product at typical summer temperatures due to the short gel time (Table 3-26). Further information is available at:
https://www.us.hilti.com/anchor-systems/injectable-adhesive-anchors/r2641

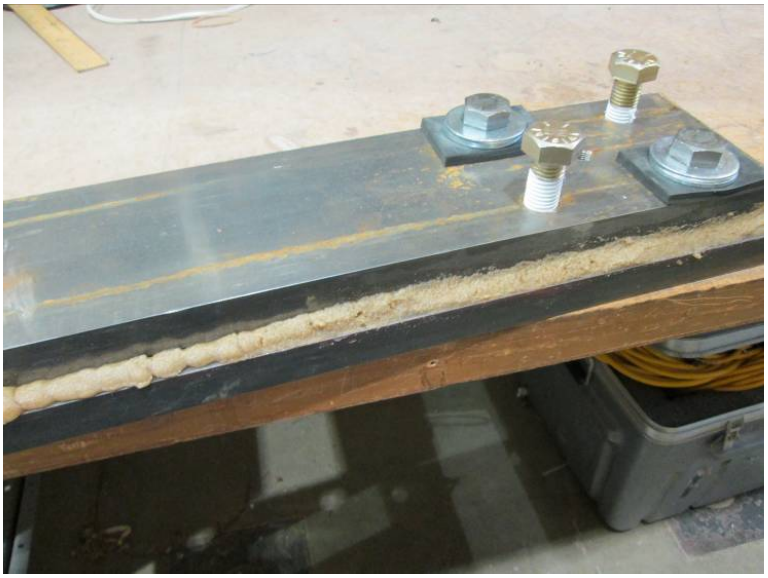
Table 3-26. Gel / full cure times for Hilti HIT ICE epoxy acrylate anchor grout.

Base Material		t_{gel}	t_{cure}
−10 °F	(−23 °C)	1.5 hrs	36 hrs
0 °F	(−18 °C)	1.5 hrs	24 hrs
23 °F	(−5 °C)	40 min	6 hrs
32 °F	(0 °C)	26 min	4 hrs
41 °F	(5 °C)	11 min	2 hrs
68 °F	(20 °C)	4 min	1 hrs
86 °F	(30 °C)	1.5 min	30 min

3.19.2 Mock quoin block test

Hilti HIT ICE is a two-component product formulated for use at temperatures below room temperature. An attempt to use it at room temperature was made to gain further insight. The entire perimeter was quickly caulked by single cartridge gun, but by the time the application completed, the first side had gelled. It could not be troweled into place. The second side was still workable and it was smoothed into place. After it was set (the next day), it was noticed that parts of the untroweled material were not forming a seal. These were re-caulked, but when head was applied, one corner was still open and leaked (Figure 3-34). This location was caulked a third time.

Figure 3-34. Application of Hilti HIT ICE on steel plates at room temperature.



Although it is likely that HIT ICE could be successfully used at room temperature, this is not recommended because:

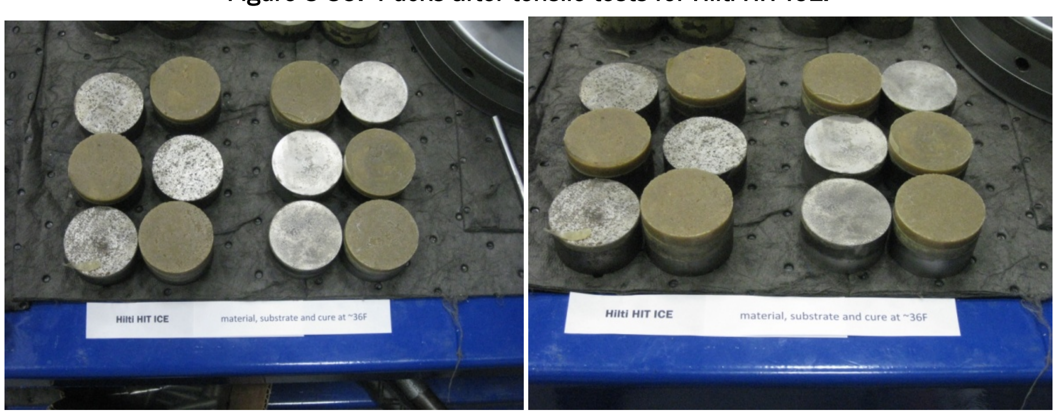
- Test samples were found to gel in about 3 minutes. This includes time in nozzle if the caulk gun is not in use. If the entire tube is used at once (or the nozzle is changed after even short gaps in usage), it might be possible to apply successfully, but working time is very short.
- This product contains fine aggregate that likely reduces adhesion and makes it slightly more difficult to work.

Note that the working time for this product is short enough to make application difficult (but not impossible, especially with numerous nozzle changes). It might be best to avoid this product at temperatures near room temperature or above. However, if a very short cure time were needed, HIT ICE might serve the purpose since it cures in less than 2 hours at temperatures above 41 °F (5 °C). This product has not been investigated at lower temperatures, but its properties suggest it could be a good option in winter conditions.

3.19.3 Tensile tests

Hilti ICE is formulated for use at low temperatures. The mock quoin block test at 75 °F (24 °C) resulted in marginally successful performance due to the very short working time. It was thought that this material might prove to be a good choice for lower temperatures. Tensile tests performed at 75/36 °F (24/2 °C) and 36 °F /36 °F (2/2 °C) were total failures (Figure 3-35). There was not enough adhesion to be able to handle the specimens and put them in the test machine.

Figure 3-35. Pucks after tensile tests for Hilti HIT ICE.



3.19.4 Discussion

At warm temperatures, the gel time for this product is far shorter than desirable and at colder temperatures, the adhesion was not adequate. Hilti ICE is not recommended for this application.

3.20 Five Star HP Anchor Grout

3.20.1 Description

Five Star HP Anchor Gel is an epoxy acrylate anchoring adhesive available in 28 oz, two-component, 10:1 mix cartridges. It is engineered for application at temperatures as low as -15 °F (–26 °C), but the manufacturer literature lists no maximum temperature. A gel time according to ASTM C-881 is listed at 10 to 15 minutes at 70 °F (21 °C) (Table 3-27). A manufacturer's technical representative stated that it sets in 2 to 3 minutes at temperatures above 85 °F (29 °C). It can be used in wet conditions. The strong odor from the uncured material suggests that breathing protection may be desirable. Manufacturer's literature lists no additional information on working, gel, cure, or load times at other temperatures. Further information is available at:
http://www.fivestarproducts.com/products/adhesives/hp-anchor-gel.html

Table 3-27. Typical properties of Five Star HP Anchor Gel epoxy acrylate anchoring adhesive.

Parameter	Property @70 °F (21 °C)
Mix Ratio	10:1 by volume
Color	Gray
Compressive Strength, ASTM D-695	10,000 psi (72.4 MPa)
Compressive Modulus, ASTM D-695	2.65 X 105 psi (1828 MPa)
Concrete Bond Strength, ASTM C-882	2800 psi (19.3 MPa) (2 days)
Concrete Bond Strength, ASTM C-882	3200 psi (22.1 MPa) (14 days)
Absorption, ASTM D-570	0.08%
Heat Deflection, ASTM D-648	144 °F (62 °C)
Elongation at Break, ASTM D-638	1.3%
Gel Time, ASTM C-881	10–15 min.

3.20.2 Mock quoin block test

Five Star HP Anchor Gel is formulated for application at cold temperatures as low as -15 °F (-26 °C) and for high early strength. Given this, maybe it is surprising that gel time at 70 °F (21 °C) is listed as 10 to 15 minutes even if working time is less than gel time. Test samples at 87 °F (31 °C) (Figure 3-36) had a working time of approximately 4½ minutes. Initially, the proof test had some small leaks, but as pressure was added, many additionally leaks developed at the grout and steel interface. This product should be re-tested at lower temperatures.

3.20.3 Tensile tests

Five Star HP is formulated for use at low temperatures. The mock quoin block test at 75 °F (24 °C) was not successful due to the development of leaks as water pressure was added. It was thought that this material might prove to be a good choice for lower temperatures. Tensile tests performed at 75/36 °F (24/2 °C) and 36/36 °F (2/2 °C) were total failures (Figure 3-37). There was not enough adhesion to be able to handle the specimens and put them in the test machine.

Figure 3-36. Test of Five Star HP Anchor Gel.

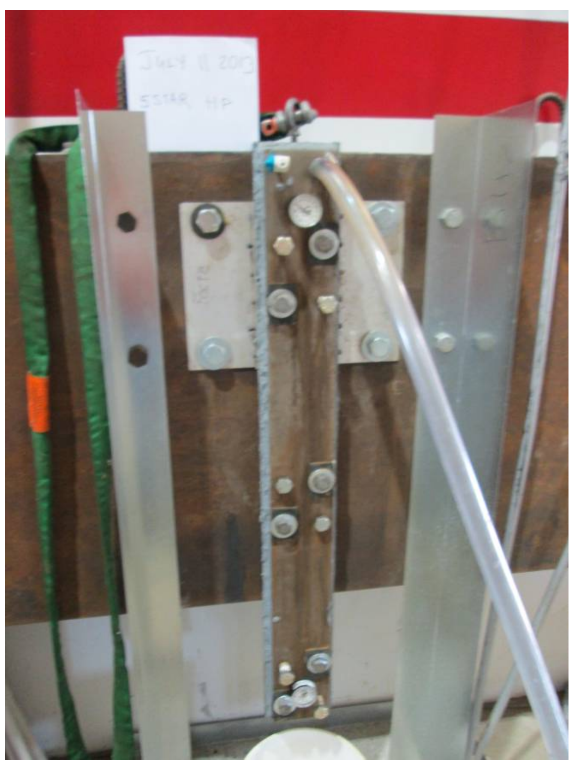
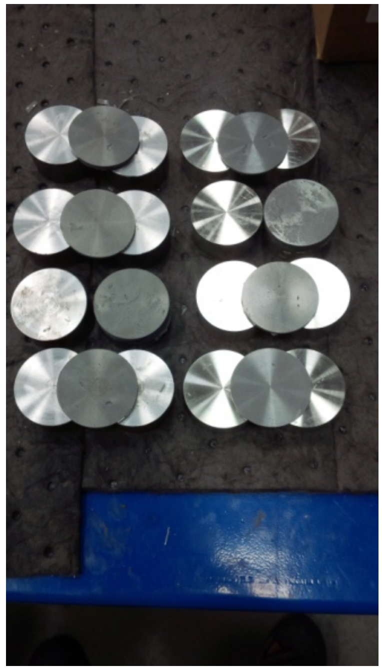


Figure 3-37. Pucks after tensile tests for Five Star HP Anchor Grout.



3.20.4 Discussion

At warm temperatures, the gel time for this product is far shorter than desirable and at colder temperatures, the adhesion was not adequate. The product in not recommended for this application

At room temperature the material failed to seal the mock quoin blocks under pressure head test. At colder temperatures the adhesion was not adequate. Five Star HP is not recommended for this application.

3.21 Redhead Epcon G5 High Strength Epoxy

3.21.1 Description

Epcon G5 is a low odor epoxy anchor grout available in 28 oz, two-component, 1:1 mix cartridges. It is specifically formulated for high temperatures and recommended for use in temperatures from 70-110 °F (21-43 °C). Given the application of concern, the temperature range may be an issue. Working time should be adequate, but the cure time of 24 hours may be longer than desired (Table 3-28). Further information is available at: http://www.itwredhead.com/product.php?G5-High-Strength-Epoxy-3

Table 3-28 lists the working and full cure times for Epcon G5 High Strength Epoxy.

Table 3-28. Working and full cure times for Epcon G5 High Strength Epoxy.

Base Material		Working Time	Full Cure Time
110 °F	(43 °C)	9 min.	24 hrs
90 °F	(32 °C)	9 min.	24 hrs
70 °F	(20 °C)	15 min.	24 hrs

3.21.2 Mock quoin block test

Redhead Epcon G5 anchoring adhesive requires temperatures above 70 °F (21 °C) to cure. When applied at 84 °F (29 °C), it did not hold position. This was particularly problematic on the horizontal edges of the plates. On the vertical edges, the material ran down the side, which proved both beneficial and detrimental. The sealer filled in nicely and needed very little tooling. In the end, although some areas had a little less material than was desired, the coverage looked adequate. While the proof test was successful, given the high degree of sag at 84 °F (29 °C) and an inability to cure below 70 °F (21 °C), the properties do not seem adequate over a large enough temperature range.

Working time was over 15 minutes at 84 °F (29 °C). It started to get more difficult to work the material at 17 to 18 minutes and the working life test was ended.

3.21.3 Tensile tests

Although the material was difficult to eject from the nozzle at room temperature, it performed adequately at this temperature (Table 3-29 and Figure 3-38).

Table 3-29. Tensile test results for Redhead Epcon G5 High Strength Epoxy.

Material Temperature	Puck and cure Temperature	Material	Average PSI	Standard deviation
70 °F (21 °C)	70 °F (21 °C)	Carbon steel	387	130
70 °F (21 °C)	70 °F (21 °C)	Stainless Steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Carbon steel	–	–
75 °F (24 °C)	90 °F (32 °C)	Stainless Steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Carbon steel	–	–
90 °F (32 °C)	90 °F (32 °C)	Stainless Steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Carbon steel	–	–
75 °F (24 °C)	36 °F (2 °C)	Stainless Steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Carbon steel	–	–
36 °F (2 °C)	36 °F (2 °C)	Stainless Steel	–	–

Figure 3-38. Pucks after tensile tests for Redhead Epcon G5 High Strength Epoxy.

3.21.4 Discussion

At 84 °F (29 °C), this material did not have viscosity to hold position for this application. At 70 °F (21 °C), it was difficult to pump the material through the nozzle. The material is not recommended for this application.

3.22 Hilti CF-ASCJP and Touch ’n Seal All Season Polyurethane Foams

3.22.1 Description

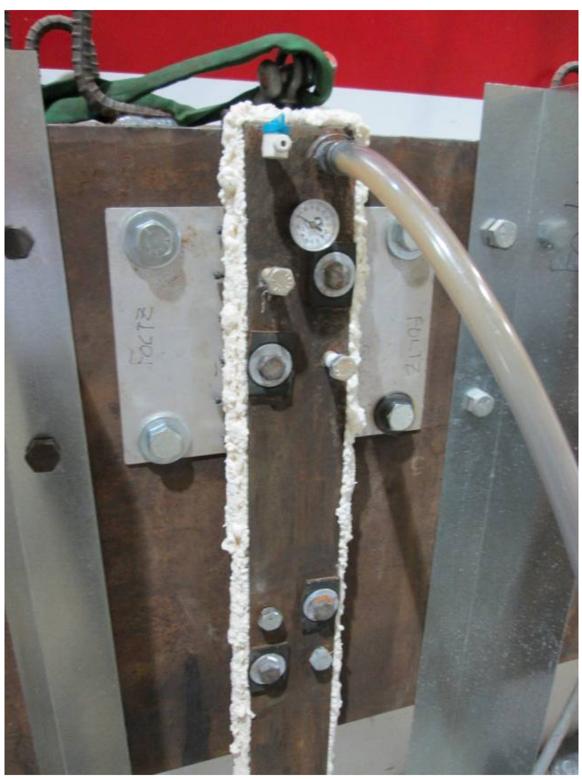
These products come in a pressurized can that attaches to an applicator. The Hilti product is intended for sealing form joints before pouring concrete. Application temperature range is from 32 to 95 °F (0 to 35 °C). The Touch ’n Seal product is for weatherproofing.

3.22.2 Mock quoin block test of Touch ’n Seal all season polyurethane foam

Touch ’n Seal all season polyurethane foam is very similar to the Hilti polyurethane foam. This product’s slightly better application and performance (Figures 3-39 and 3-40) may have been attributable to improved application technique. It was still difficult to apply this product uniformly. One area developed many large leaks.

Figure 3-39. Test of Touch ’n Seal all season polyurethane foam.

Figure 3-40. Close-up view of Touch ’n Seal all season polyurethane foam application.



With increasing head (~10 ft), a number of small leaks developed in other areas. On disassembly, it was clear that adhesion was variable. It is not clear whether this was due to surface conditions, application technique, or a combination of the two. Regardless, the foam does not appear to be a good candidate. It seems to work best when filling a three-sided void or deep cracks or joints. In this case, the primary location of the seal was a different configuration.

3.22.3 Mock quoin block test of Hilti Foam CF-ASCJP on plexiglas plates

The Hilti Foam CF-ASCJP foam seemed to apply rather well (Figure 3-41). Foam was applied in multiple (3 to 4) passes. When head was applied, a small leak became immediately apparent. With about 10 ft of head, a much larger leak opened at a different location. While it is possible that the foam would perform better on steel, this is not recommended because:

- The foam bled into the backing material cavity (not nearly as badly as expected).
- To minimize bleed into the backing material cavity, the caulk beads were applied in relatively small quantities, in multiple passes. This application process increases the odds of inadvertent gaps (Figure 3-42).
- It was difficult to visually verify a watertight application of the foam.

3.22.4 Mock quoin block test of Hilti Foam CF-ASCJP on steel plates

Hilti Foam CF-ASCJP was applied by an alternate person who claimed substantial experience in applying foam caulking. The results were similar or worse than the previous person applying the foam on the Plexiglas. Numerous holes were evident when water pressure was applied. The steel plates were not re-caulked to determine the head pressure resistance. Those present expressed the opinion that it was difficult to apply the foam in a waterproof bead and even more difficult to verify the seal by inspection.

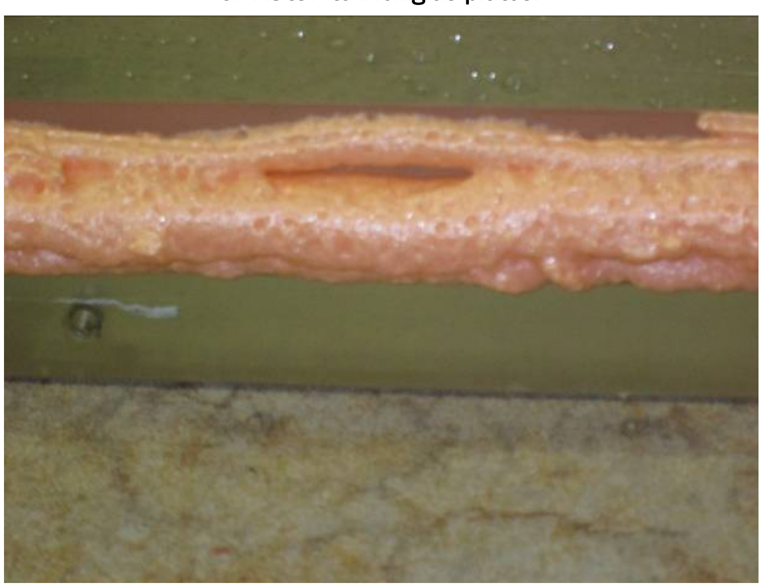
3.23 One-part silicone caulk (generic)

3.23.1 Description

The silicone caulk used was an exterior grade weather stripping product meeting ASTM C920 specifications.

Figure 3-41. Application of Hilti foam CF-ASCJP to Plexiglas plates.

Figure 3-42. Gap in application of Hilti foam CF-ASCJP to Plexiglas plates.



3.23.2 Mock quoin block test of silicone caulk on plexiglas plates

This caulk was applied, but was not worked into the gap or the corner of the two plates (Figure 3-43). The test was run after approximately 20 hours. When head was applied, small leaks were immediately apparent and the caulk failed much more extensively with only minimal head pressure. When the caulk and plates were separated, it was determined that, while the exterior surface of the caulk was firm, dry, and generally cured, the interior was still soft and sticky. This raised concerns that a one-component product may not be the best choice for this application.

Figure 3-43. Setup for test of silicone caulk on Plexiglas plates.

3.24 One-part polyurethane caulk (generic)

3.24.1 Description

The polyurethane caulk used was an exterior grade weather stripping product meeting ASTM C920 specifications.

3.24.2 Mock quoin block test of polyurethane caulk on plexiglas plates

This polyurethane caulk was applied and worked into the gap or corner of the two plates. The test was run after approximately 20 hours. When head was applied, the seal appeared to be good, but the caulk failed with only minimal head pressure. When the caulk and plates were separated, it was determined that, while the exterior surface of the caulk was firm, dry, and generally cured, the interior was still soft and sticky. This confirmed concerns that a one-component product may not be the best choice for this application.

3.25 3M™ Scotch-Weld™ Epoxy Adhesive DP420

3.25.1 Description

3M Scotch-Weld DP420 is a two-part epoxy adhesive. It is a low viscosity product designed for thin layer applications.

3.25.2 Mock quoin block test

3M™ Scotch-Weld™ epoxy adhesive DP420 has a room temperature viscosity of 30,000 centipoises. When applied at 82 °F (28 °C), it was not thick enough to hold its place while attempting to fill the gap between the steel plates. The application was not completed.

4 Conclusions and Recommendations

4.1 Conclusions

Based on test results summarized in this report, this work concludes that a number of materials will work for the target application, i.e., best practices for sealing the perimeter of cavities behind quoin and miter blocks before pouring backing materials in those gaps.

Based on these test results, this work also concludes that there are many potential paths to failure, many of which are avoidable, specifically:

- not creating a continuous seal (application and tooling).
- applying materials to a dirty, greasy, and or corroded surface that reduces adhesion.
- using expired or improperly stored materials.
- creating or leaving gaps or holes in coverage.
- using materials that are improperly mixed or not appropriate for the temperature.
- using materials at low temperatures. (At low temperatures, all materials performed worse in these tests. Some were unusable, but even those with satisfactory results did not perform as well as at higher temperatures.)

Some paths to failure appear random and may not be avoidable. In particular, in apparently random circumstances, two materials did not set or cure despite otherwise displaying good performance.

In all cases, the target application discussed in this report is an "off label" use of the tested materials. The tests summarized in this report should — at best — provide a preliminary guide to performance that should be expected in the field under more varied conditions. The tests did not account for all variables that could affect success.

Temperature is an important variable in field application of the sealing materials tested in this work. An attempt was made to test materials in "summer temperatures," from approximately 70 to over 90 °F (21 to over 32 °C). Material properties clearly varied over this range. Many of the products were only tested once using the pressure tested quoin or mock quoin block setup, but some were tested at two temperatures: 70 °F

(21 °C), approximately room temperature, and 90 °F (32 °C). Most materials were tensile tested at multiple temperatures, with some exceptions based on manufacturer recommendations temperatures, to gain insight into performance over a range of temperature. Most materials had lower tensile-adhesive strengths at lower temperatures.

Most products tested have a specific recommended temperature range for designed applications. For use as described in this report, the viable range is typically shorter due to loss of viscosity and short working times at higher temperatures. Vendors of some materials provide no recommended temperature range, apparently on the assumption that application temperatures will be near room temperature.

Most of the materials tested were epoxy grouts, many of which contain silica aggregate. Testing raised concerns about the adhesion between products with this material and a relatively smooth steel surface. At least one vendor concurred. For unidentified reasons that may or may not be related to the aggregate, none of these materials performed satisfactorily at lower temperature.

The pressure tests were performed using water instead of an epoxy backing compound. This more stringent condition led to conservative results.

4.2 Application recommendations

In the preliminary testing discussed in this report, a rotary wire brush was used to prepare the surface. This clean bare metal was in some cases left wetted to create a surface corrosion. Numerous materials showed good adhesion to the bare metal and the mildly corroded surface. It is recommended that application surfaces be washed with a mild detergent and wire brushed or bristle blasted to obtain a bare metal surface.

While the laboratory conditions were not tightly controlled, field conditions will generally be more severe. At a minimum, this work was completed with “feet on the ground” instead of using a man-basket, lift bucket, or scaffolding. Under field conditions, wind, rain, sun, etc. are also factors. Despite this relative advantage, it was surprisingly easy to leave small holes or gaps in the coverage. This may be partially due to lighting or the material color.

In the process of applying the two-component tubes in applicator with mixing nozzle products, many "lessons learned" were drawn from discussions with the material vendors, from trial and error:

- Based on laboratory test setups, it appears that many two-component products applied through cartridges and mixing nozzles would be effective and convenient, and could be applied relatively quickly in the field. This testing also determined that some of these materials would not be satisfactory. No quick method of identifying the satisfactory and unsatisfactory was determined. Material testing appears to be the only option.
- Working times and cure times vary significantly between products. Product selection would depend on the temperature at the time of use. Some materials have larger effective ranges than others. Some are better for winter temperatures, others for summer.
- Most of these materials have a shelf life of 1-2 years, some even less than a year. In multiple cases, expired materials were delivered. Some of these expired materials did not perform as well as the unexpired replacements. Many of the products are marked with lot numbers, but were not marked with an expiration date. The manufacturers were contacted to ascertain the expiration. Given that four tested materials were expired when delivered, verification of expiration date is recommended before field use.
- Most materials have a recommended storage temperature. Although recommendations vary by material, they usually span the normal conditioned room temperature range.
- Before use, the tubes should be vertically oriented with the top outlet "up" long enough to allow any air to rise to the top. Before attaching the nozzle, a small amount to material should be squeezed out to even the flow between the two components.
- While applying, air bubbles indicate improper mixing. This material should be removed and replaced to avoid applying improperly mixed material, which may not cure properly.
- When the tube in use is left to sit, the material in the nozzle can partially cure. This poorly mixed, partially cured material should be cleared and disposed before continuing application.
- Partially used tubes can be stored for at least a few days with the old nozzle still attached. To reuse the partially used tube, remove the old nozzle and pump a small amount of material out to waste before attaching a new nozzle.

4.3 Recommendations for further testing

Testing was limited by the funding available. This was also the reason for using the tensile tests, which proved to be a valuable complement to the mock quoin block tests. Many of the materials could be further tested to confirm results and verify performance under other conditions, including higher temperatures.

It is recommended that further tests be performed to evaluate the effect of moisture on the cure of the materials.

Although the steel used in these tests could be considered representative, it is recommended that testing be done using steel with different surface conditions to determine the effect of various typical steel surface conditions on the behavior of the tested sealing materials.

4.4 Product recommendations

Based on the testing described in this report, the following materials are recommended for warm weather use to seal the space behind miter gate contact blocks before pouring filler materials. Note that each material had its advantages and disadvantages:

- Liquid Roc 300 twin tube. The adhesion to steel was very good. Working time at warm temperatures is less than might be preferred, but should be adequate.
- Hilti HIT RE500. This material was easiest to apply. Working time was good and it did not sag. The gel time should be adequate at the highest temperatures, but the cure time may be longer than desirable for the contact block application, especially at lower temperatures.
- Loctite Fixmaster® anchor bolt grout HP. The adhesion to steel was good. Working time at warm temperatures was good. This material sagged more than the other recommended materials, but it was judged to be acceptable. The cure time may be longer than desirable for the contact block application, especially at lower temperatures.
- W.R. Meadows Polygrip. The adhesion to steel was very good. Working time at warm temperatures is less than might be preferred, but should be adequate. Note that tensile tests could not be completed at some temperatures.
- Bondo®. Because Bondo® is hand-mixed in proportions chosen by the user, it offers great flexibility, but also opportunity for error. Hand-

mixed products typically take longer to apply, but if they give good results, that should not be a disqualifying factor.
- Splash zone A788. A788 is hand mixed in a relatively time consuming process. It has the advantage of a very long working time and good results in wet environments. It had good bond to the steel, but the material strength is generally less than the other materials.
- The two seam sealer products and Loctite 5607 do not have manufacturer recommendations for application other than at room temperature. Their performance was generally adequate, but further testing is needed before this product can be recommended without reservation.

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Acronyms and Abbreviations

Term	Definition
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
ERDC	Engineer Research and Development Center
HP	High Performance
HQUSACE	Headquarters, U.S. Army Corps of Engineers
L&D	Lock and Dam (L&D)
LRD	Great Lakes and Ohio River Division
NSN	National Supply Number
OMB	Office of Management and Budget
TD	Technical Director
TR	Technical Report
UFGS	Unified Facilities Guide Specification
UPC	Uniform Plumbing Code
URL	Universal Resource Locator
U.S.	United States
USACE	U.S. Army Corps of Engineers
WWW	World Wide Web

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14. ABSTRACT
Unified Facility Guide Specifications (UFGS) 35 20 16.33 "Miter Gates," specifies two types of filler materials to set miter and quoin contact blocks: epoxy and zinc. Zinc is rarely used today for safety reasons. While the epoxy filler stipulated in the guide specification is no longer available, the UFGS does permit the use of an equal product, and several are being used effectively in the field. The materials currently in use have low viscosities and are typically poured behind the quoin and miter blocks in sections. Gaps are typically sealed with commercial fillers. Often, the surface preparation on the quoin block and channel is not ideal for proper adhesion. This is not a problem for the epoxy filler materials since they are applied in a confined space and are loaded in compression. However, the sealing materials can fail as the pressure head of the epoxy material increases while it is being poured. This pressure can cause the epoxy material to leak out. When this happens, the gap must be cleaned and resealed. This work was undertaken to resolve the problems associated with pouring epoxy fillers, and to recommend improvements to the process.

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